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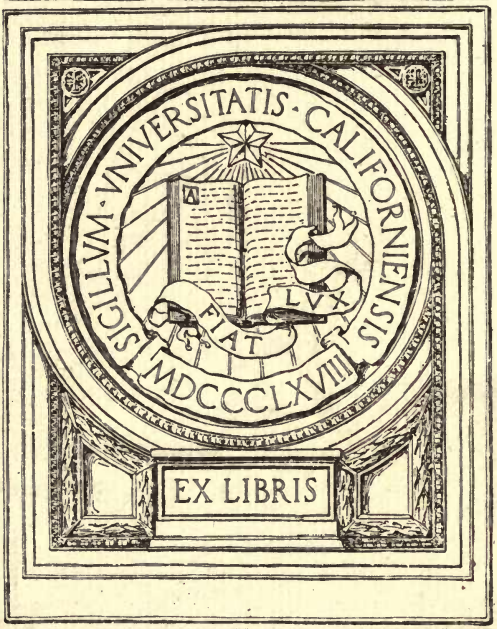
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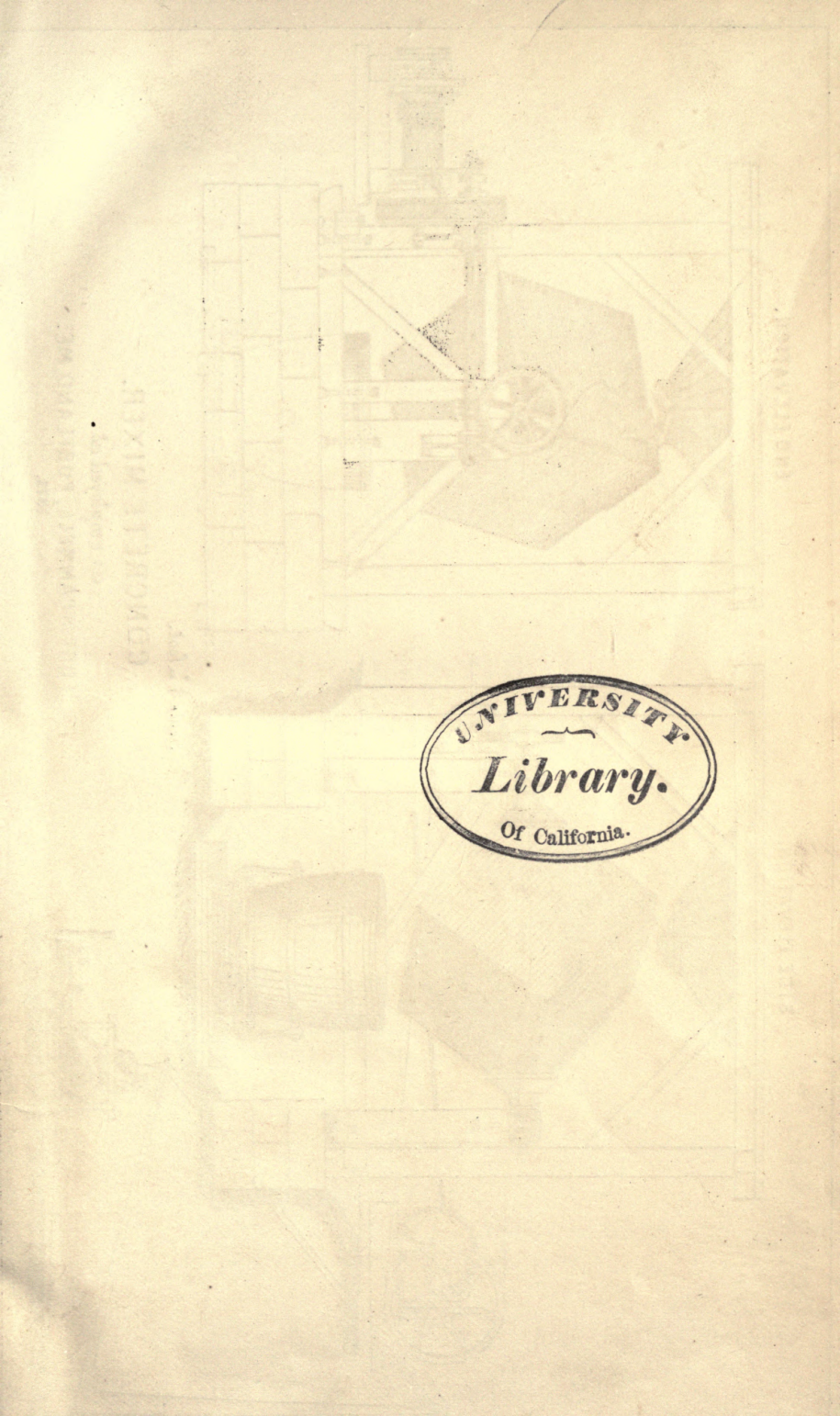
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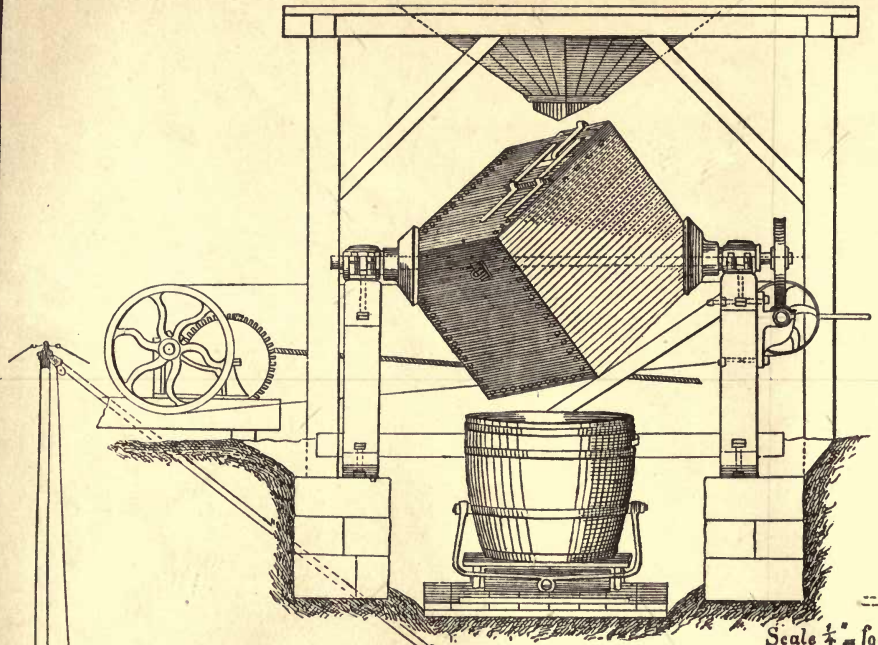

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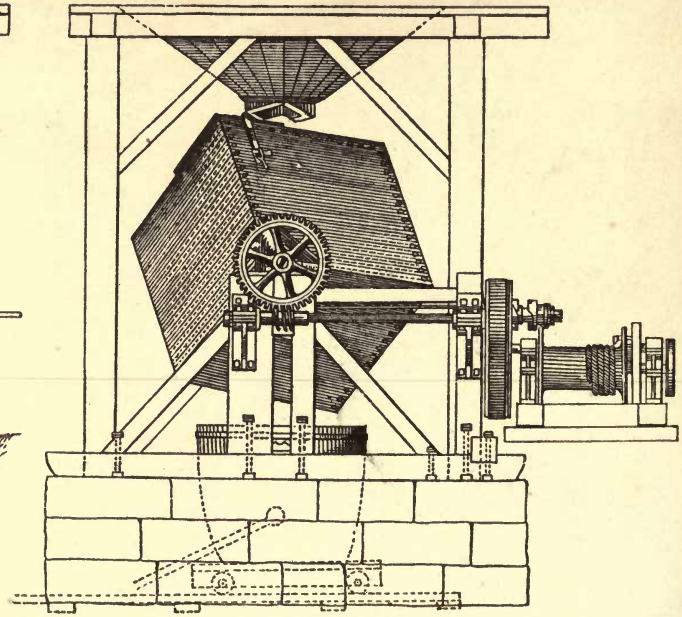
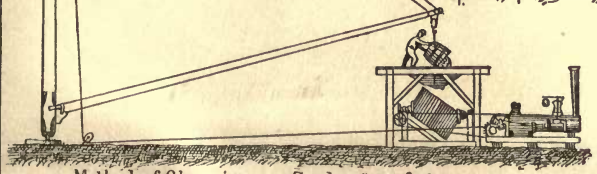


CONCRETE MIXER.

as employed at

FORT SCAMMELL, PORTLAND, ME.

1871.



Method of Charging.— Scale 1" = 24 feet.

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No. 9.

PRACTICAL TREATISE

ON

LIMES HYDRAULIC CEMENTS,

AND

MORTARS.

BY

Q. A. GILLMORE, A.M.,

Lieutenant-Colonel U. S. Corps of Engineers, Brevet Major-Gen. U. S. Army.

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NOTE.

The experiments and researches, which furnish the groundwork for all the original matter contained in the following work, were conducted under the authority of the Engineer Bureau of the War Department, and were completed in the summer of 1861. The manuscript was nearly ready for the publisher at the same time.

Since then, active professional duties have rendered it impossible for me to devote even a brief personal superintendence to the publication of the work. I am, therefore, not insensible to the many disadvantages under which its hasty publication is now undertaken. It doubtless contains many defects.

For the method of analysis given in Chapter V., I am indebted to Captain E. C. Boynton, U. S. Army, late Professor of Chemistry in the University of Mississippi.

Q. A. GILLMORE,
Brig.-General.

Head-Quarters, Dept. of the South,
Port Royal, S. C., *June* 15, 1863.

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PREFACE TO THE FOURTH EDITION.

In preparing the fourth edition of this work for the press, it has been thought proper to give, in an Appendix, brief descriptions of the two methods, one by hand and the other by machinery, followed in making the several qualities of Portland cement concrete, applied, for various purposes, in the construction of the fortifications on Staten Island, New York Harbor, of which the author has charge as superintending Engineer.

The special information given has been derived from the experience of two working seasons—1870 and 1871—and all the data with regard to the cost and proportions of the constituent ingredients—the cement, lime, sand, gravel, and broken stone—as well as the cost of the finished concrete in position, may be relied upon as correct, within reasonable limits.

The Appendix also contains a description of the new concrete mixer, in use on the works, a drawing of which serves as a frontispiece to this edition.

A new and carefully prepared index has been inserted in place of the old one, and the work has been, in other respects, essentially revised and improved.

Q. A. GILLMORE,
Bvt. Major-General, U.S.A.

New York, January, 1872.

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A PRACTICAL TREATISE

ON

LIMES, HYDRAULIC CEMENTS, AND MORTARS.

CHAPTER I.

INTRODUCTION.

1. NATURE has supplied us with limestones in great profusion and endless variety. Those suitable for common lime are so widely diffused, and have such an extensive development in this country, that no attempt will be made,—nor would it be consistent with the character and scope of a work devoted to the consideration of "mortars," even under the most comprehensive signification of that term,—to particularize the numerous localities where its manufacture is extensively and successfully carried on.

An abundance of common limestones in the United States.

2. Impure or compound limestones, possessing the property of hardening under water after being calcined, and reduced by slaking, or by the aid of mechanical means, to the state of paste, although more rare than the common limestones, nevertheless occur in numerous localities in the United States; and from the great and peculiar value, as a cementing material for submarine and subterranean constructions, of the mortars derived from them, they merit a more detailed notice.

Compound limestones also occur in numerous localities.

3. The most extensive beds have thus far been discovered in the valleys of the great Appalachian chain of mountains, as they traverse the States of New York, New Jersey, Pennsyl-

vania, Virginia, Tennessee, and the northern portions of Georgia and Alabama. They are, however, by no means confined to those States, but have been found to some extent in the northern terminus of this range, as it passes through Massachusetts and Vermont, at the forks of the Kennebeck, and other places in Maine, and in the northern counties of Mississippi. In a westerly direction, and beyond the lateral limits of the great Appalachian Valley, in the western regions of New York, Pennsylvania, Virginia, and Tennessee, as well as in Kentucky, Ohio, Indiana, and Illinois, the same kind of stone exists in numerous and extensive deposits.

4. There is no geological formation to which the term "hydraulic lime" or "hydraulic cement" can with propriety be exclusively applied, inasmuch as we find none which, over extensive areas, and in localities widely separated, is capable of furnishing uniformly either the one or the other of these products. All sedimentary rocks are noted for the marked variations in their lithological characters, within very limited areas, owing to the existence of local causes, affecting the conditions of their deposition. This is specially the case with those impure limestones of which the composition is such as to render them, as an exceptional class, suitable for hydraulic mortars,—a circumstance due to their peculiar geological position. They usually contain, in widely varying proportions, carbonate of lime, carbonate of magnesia, silica, alumina, oxide of iron, and a small amount of alkali, and are generally comprised in the beds of passage between deposits that are purely silicious or argillaceous, and those that are purely calcareous or dolomitic. They therefore, in the general case, derive their character from the contiguous underlying and overlying rocks, and approximate more intimately to the one or to the other, in proportion as the causes operating during the period of formation unduly favored its deposition. If a limestone, for example, was formed upon a sandstone, by the

The character of stone suitable for hydraulic lime or cement is very variable.

The usual ingredients the same.

gradual and progressive subsidence of calcareous particles, commenced and carried on before the deposition of the silicious matter was completed, the intermediate beds created by this mingling process would be a silicious limestone, with proportions depending on the manner of deposition, and the nature and extent of the causes by which it was produced and regulated. It could be uniform only while those causes remained fixed and persistent. The intervention of local disturbances of whatever extent or character, tending to hasten, retard, or render intermittent the deposition of either of the principal ingredients, would of course modify their proportions, and materially affect the character and properties of the compound rock.

5. Observations show that the argillaceous and argillo-magnesian limestones of the United States are characterized, in an eminent degree, by variations in composition, due to such causes; and that these variations frequently, and, in fact, generally, occur within very short distances.

6. At the base of the Lower Silurian System we find the Potsdam Sandstone, the lowest known fossiliferous rock, and interesting in this connection from the fact that it, in a measure, imparts hydraulic character (by supplying the silica) to the calcareous deposits resting upon it. In New York, this sandstone is a firm quartzose rock; while, in some portions of the West, the cohesion between the particles is so slight that it can be easily crumbled in the hand. It occurs of various shades of yellow, red, and gray, approaching to white, and is most intimately related to the calcareous beds which underlie it. In many places, it gradually passes into easily recognized compact magnesian limestone, sometimes alternating with the calcareous beds above. This sandstone corresponds to Formation I. of Prof. Rogers' classification of the rocks of Pennsylvania and Virginia.

The Potsdam Sandstone underlies the lowest calcareous beds possessing hydraulicity.

7. The next rock in the ascending series belongs to Formation II., known as the calcareous "sandrock," or, more com-

monly, "calciferous group," which, in both composition and age, must be regarded as intermediate between the Potsdam Sandstone and the purer limestones above, viz.: the Chazy, Bird's Eye, Black River, and Trenton Groups. It is the oldest known fossiliferous limestone, is calcareo-silicious in character, as its name indicates, and is the lowest member of the series capable of yielding either hydraulic lime or cement. In many localities, it exhibits the water-lined laminæ of deposition in a marked and conspicuous degree.

"Calciferous Group."

Three distinct masses of this rock are usually observed wherever it presents a fully developed outcrop.

8. The *lowest* beds are highly silicious, and in the eastern portions of the United States, where it has been most examined, quite compact, being undoubtedly produced by a partial continuation of the Potsdam Sandstone deposit, carried on simultaneously with that of the calcareous matter, the composition of the rock showing a notable excess of the former.

Its *lower*, *middle*, and *upper* subdivisions.

9. The *middle* beds appear to comprise a variable mixture of yellowish sand and carbonate of lime, presenting, when newly broken, a gritty and sparkling fracture. They are those to which the term "Calciferous Sandrock" is usually applied.

10. The *upper* or superior mass more nearly approximates in character to the limestones above, and is very frequently intermixed with argillaceous matter. The appearance of a recent fracture is granular and sparkling, and often exhibits a sub-crystalline structure. This rock, however, assumes at different points a remarkable diversity in both its physical appearance and its chemical composition. It is synonymous with the Barnegat, Newburgh, Warwick, Oolitic, and Slaty limestones, the Transition Sandrock of Eaton and the Fucoidal Layers, and with the Magnesian limestones of the West.

11. The purer calcareous beds which rest immediately upon

the "Calciferous Group" also belong to Formation II. of Prof. Rogers' classification, and are known at different points as the Black River limestone, the base of the Trenton limestone, the Mohawk, Bird's Eye, Bald Mountain, Blue, and Chazy limestones, the Transition Limerock of Eaton, Blue limestone of Kittatinny Valley, Pennsylvania; and, in the West, as the Fossiliferous limestones, and the Blue limestones and marls. These beds are frequently connected very intimately with the members of the group below, and, in numerous localities, possess in suitable proportions, and in proper combination, those ingredients which confer the hydraulic property.

The calcareous beds resting on the "Calciferous Group" suitable for hydraulic mortar.

12. It is unnecessary for our purpose, in a work like this,—in which rocks of a particular class, and bearing a close resemblance to each other in their general features, are discussed specially with reference to their adaptation to a particular use,—that all the technicalities of a strictly geological classification should be kept constantly in view. It will be sufficient to intimate, in brief terms, that among those deposits lying above the Potsdam Sandstone, and below the Utica Slate or its corresponding member, all of which are comprised in Prof. Rogers' Formation II., are found in numerous places extensive beds of argillo-magnesian limestone, possessing the hydraulic energy in a high degree; and that these beds occur sometimes higher, and sometimes lower in the series, as determined by causes operating during the period of their formation. They have an extensive development in the United States, particularly along the great Appalachian range.

Between the Potsdam Sandstone and the Utica Slate, many argillo-magnesian deposits possess hydraulic energy.

13. In the State of New York, they occupy a narrow belt along the eastern portion of the State, extending from the Vermont line in a southerly direction through Williamstown, Lebanon Springs, Pine Plains, Barnegat, and Newburgh; thence stretching in generally parallel strips in a southwesterly direction towards the

Geographical localities of the principal outcrops in New York.

New Jersey State line, which it crosses between Unionville and the Long Pond. The same stone is also brought to the surface repeatedly in New York, in the counties of Montgomery, Herkimer, Oneida, Lewis, Warren, Clinton, and Jefferson. In but few of the localities mentioned is the stone manufactured into hydraulic cement, and in none, perhaps, have its full capabilities in this regard been ascertained by adequate experimental tests.

14. Within the State of New Jersey this formation continues its course, exhibiting extensive outcrops, lying generally within the limits of a belt or zone from twenty to twenty-five miles in width, which intersects the Delaware River in the vicinity of its confluence with the Lehigh. It then crosses into the State of Pennsylvania, and spreads itself over a large tract in the eastern portion of that State, southeast of Kittatinny valley, in Lehigh, Berks, Chester, Lancaster, and York counties, and elsewhere.

In New Jersey.

15. In Virginia the limestones of this formation also exist in numerous and extensive beds in the counties of Rockingham, Botetourt, Roanoke, Washington, Rockbridge, Page, Augusta, Giles, and Shenandoah. Cement from the James River and Kanawha Canal has, for several years, been manufactured at Balcony Falls, Rockbridge County. At the present time cement for constructing the Covington and Ohio Railroad is derived from Dunlop's Creek, a tributary of the James River, a few miles above Covington. There are three cement manufactories on the Potomac River: one at Shepherdstown, Va., another three miles above Hancock, Md., and another at Cumberland, Md. From the present state of our knowledge, it would be inferred that the beds belonging to this formation in Virginia and Pennsylvania are better calculated to furnish a reliable cement than those found in the more northern parts of the range. In New York, one member of the series—the Black River limestone—was

In Virginia.

The Virginian and Pennsylvanian deposits presumed to be of superior quality to those farther North.

formerly made into cement at and near Galesville, Washington County, for the Champlain Canal. At Point-aux-Roches, on Lake Champlain, a bed of it five to six feet in thickness exists, which possesses a good degree of hydraulic energy, but has never been manufactured for the market. The same stratum has been found to yield only hydraulic lime in some localities, and has been used for that purpose at Lowville, Lewis County, N. Y.

16. Among the many analyses that have from time to time been made of specimens from the various deposits of these limestones, those in Table I. have been selected from the most reliable sources of information which were at command. It is proper to remark in this connection, that those given in the table,—having been derived from State Geological Reports, principally, for the general purposes of which they are doubtless sufficiently exact,—ought not, perhaps, to be implicitly relied upon, as the basis of any special or critical research upon the subject of hydraulic mortars and the theory of sub-aqueous induration. None of them show the presence of either potash or soda in any form. It is well known, however, that the salts of both these substances exist in some of the quarries examined, and it is fair to infer, from the close resemblance otherwise preserved in the nature and proportion of the constituent parts, that adequate tests would detect a notable quantity in all. The Rosendale cements contain them. An easy process for detecting their presence, and measuring their quantity, has yet to be discovered, which may account for the fact that their existence in this class of rocks is so very generally ignored.*

Analysis of the above-mentioned limestones.

Soda and potash probably exist in all cements.

Not easily detected and measured.

* M. Fred. Kuhlmann, Professor of Chemistry at Lille, and Corresponding Member of the Institut de France, submitted a report to the Academy of Sciences of France in 1841, from which the following extract is taken. The subsequent writings of M. Kuhlmann, down to a period quite recent, sustain the opinions here

TABLE I.

ANALYSIS OF SEVERAL OF THE OLDEST FOSSILIFEROUS LIMESTONES OCCUPYING POSITIONS BETWEEN THE POTSDAM SANDSTONE AND THE UTICA SLATE.

	Trap Dyke, Rockingham Co., Va.	Prince Mountain, Botetourt Co., Va.	3 miles North of Big Lick, Roanoke Co., Va.	Rich Valley, Washington Co., Va.	Nr. Cedar Grove, Rockbridge Co., Va.	Shenandoah River, Page Co., Va.	4 miles South of Newmarket, Shenandoah Co., Va.	Near Waynesboro', Augusta Co., Va.	Near the mouth of Wolf Creek, Giles Co., Va.	Lafayette, Sussex Co., N. J.	Johnsonburg, Warren Co., N. J.	South of the Paulinsill River, between Newton and Swartswout's Pond.	Anderson, Warren Co., N. J.	Point-aux-Roches, Lake Champlain.
Cabonate of lime.....	54.	52.	46.5	50.1	50.1	52.	54.	49.3	52.9	53.	53.5	54.9	53.6	53.3
Carbonate of magnesia.....	42.5	37.5	34.5	41.5	35.8	41.8	42.5	38.3	44.	41.1	38.8	34.	41.6	22.6
Alumina and oxide of iron..	1.5	1.5	4.	.7	2.1	1.2	.7	2.3	.6	1.	.7	2.1	1.4	1.7
Silica	1.5	8.5	13.	7.4	11.3	4.7	2.4	9.4	2.2	3.2	6.3	7.5	3.4	20.7
Sulphuret of iron.....			1.											
Carbonate of potash and soda														.0½
Water and loss	.5	.5	1.	.3	.7	.3	.4	.7	.3	1.7	.7	1.5		1.6½

17. After passing the argillo-magnesian limestones associated with the "Calciferous Sandrock," and intermediate in lithological features between this rock and the purer limestones above, we meet with no calcareous deposit suitable for hydraulic cement until we reach, in the ascending order, the Niagara Group of the Ontario Division, among the beds of passage from the shale to the limestone of that group. Here is found an argillaceous limestone brought to the surface repeatedly in the State of New York, in Wayne County, and in the towns of Rose, Williamson, and Ogden, in Monroe County. This

No cement stone between the Utica Slate and the Niagara Group of the Ontario Division.

expressed as to the general prevalence of the alkaline salts in the hydraulic limes and cements of Europe.

Extract.—In speaking of the nature of the efflorescences upon walls, he says: "Mes investigations sur ce point m'ont permis de constater la présence de la potasse ou de la soude dans la plupart des calcaires de diverses époques géologiques, et de justifier l'existence de ces alcalis dans les végétaux qui croissent sur un sol calcaire." M. K. also analyzed the cements of Pouilly, Vassy-les-Avallon, Boulogne, and the Roman cement from the Septaria, taken from the banks of the Thames, and found potash in all of them, notwithstanding the confirmed opinion of chemists that they contain no alkaline ingredient. American cements contain chlorides of potassium and sodium generally, sometimes as high as 7 per cent.

deposit exposes very good cement stone in Orleans County, at Oak Orchard Creek, town of Shelby, and at Farwell's Mills, town of Clarendon; also in Niagara County, at Lewiston. Among these beds of passage, only those occupying a central position can be relied upon for hydraulic mortar, the layers above being, as a general thing, too highly charged with carbonate of lime, while those below contain too much clay.

18. Overlying the Niagara Group, we find, in the Helderberg division, a limestone among the upper beds of the Onondaga Salt group, sometimes called the Magnesian deposit of that group, which furnishes nearly all the hydraulic cement manufactured in the western part of the State of New York. It appears on the eastern shore of the Cayuga Lake, and further west, in Phelps and Manchester townships, Ontario County, at Williamsville, Grand Island, and Akron, Erie County. At East Vienna it has been used for cement, and at Akron a manufactory of some extent is in operation now.

"Magnesian Deposit" of the Onondaga Salt group.

At Morgantown, Genesee County, and at Black Rock, Erie County, the limestones of this group have an extensive development in connection with those of the Water Lime Group proper. Its full thickness is seen at the Falls of Falkirk. It underlies the village of Caledonia, Livingston County, extending thence easterly towards the Genesee River, and, reappearing on the other side of that stream, is found at Mendon, Monroe County, and other neighboring localities.

19. Beyond the limits of the State of New York, the layers above mentioned are not found possessing such prominent features as to entitle them to a distinct and separate description, but are included in the contiguous groups under a more general classification.

20. Overlying the Onondaga Salt Group, in regular succession, is found, along the great Appalachian range, the Tentaculate, or Water limestone, from which a very large proportion—perhaps nine-tenths—of

"Tentaculate" or "Water lime" deposit.

the hydraulic cement manufactured in the United States is derived. It appears to be wanting in the Western States, or to have been replaced by the Cliff limestone of Ohio. In New York, it is found in large quantities in Oneida, Onondaga, Madison, Ulster, Sullivan, and Erie Counties. Its principal deposit is in Ulster County, where it furnishes the celebrated Rosendale cement,* so extensively used on the government works on the Atlantic, Gulf, and Pacific coasts, and along the northern frontier. It is quarried for cement at Manlius and Fayetteville, Onondaga County, and Chittenango, Madison County. The cements from these localities vary very much in quality. A cement manufactory is also carried on at Lockport, Niagara County. The stone that may be used for cement, occurring frequently along the line of the Erie Canal, occupies, with some local exceptions, two geological positions quite distinct from each other. The lowest layers are mostly confined to the beds of passage from the shale of the Niagara Group to the purer limestones above, while the others are similarly situated with reference to the marls and shales of the Onondaga Salt Group and the purer calcareous beds which overlie them. In either position, great care is requisite in selecting the stone for burning, the best cement being generally confined to the middle of these beds of passage—those below being too argillaceous, those above too calcareous.

Geographical localities of the principal beds.

General character of the cement stone along the Erie Canal.

21. Reserving a more detailed and minute description of the Ulster County deposits for a subsequent part of this work, we will here simply state that they are mostly found within the limits of a narrow belt, scarcely one mile in width, skirting the northwestern base of the Shawangunk Mountains, along the line of the Delaware and Hudson Canal, in the valley of Rondout Creek. They are

Principal deposits of "Rosendale Cement" stone.

* Named from the town of Rosendale, in which the cement was first discovered and manufactured, during the construction of the Delaware and Hudson Canal.

not, however, confined to this locality, but can be traced in a southwesterly direction through Ulster and Sullivan Counties to the State Line at Carpenter's Point, and thence, within the State of New Jersey, in a narrow strip along the left bank of the Delaware River, to Walpack's Bend, where they cross over into the State of Pennsylvania. In a northerly direction, this rock has not been distinctly recognized east of the Hudson River. At the mouth of Rondout Creek the belt takes a turn due north, and can be correctly followed along the right bank of the Hudson, a distance of five or six miles, with occasional glimpses of it in detached masses ten or twelve miles higher up. Except in Ulster County, towards the northern terminus of the range, these beds have not been manufactured into cement, and have not, it is believed, been very critically examined with that view.

22. The only limestone in Massachusetts that has ever been employed for hydraulic mortar is that at Paine's Quarry, West Springfield. It is said to be very good hydraulic lime, and contains, by analysis, .93½ of carbonate of lime, .5$\frac{6}{10}$ of argillaceous clay, and less than .1 of carbonate of magnesia. Another hydraulic limestone that has been tried, but never worked, is found in the bed of the Chicopee River, just below the Chicopee Factory. It contains .86$\frac{8}{10}$ of carbonate of lime, and .13$\frac{2}{10}$ of argillaceous clay. Both of the stones just mentioned are fetid and partially bituminous. They belong to the new Red Sandstone formation. Nodules of Septaria are found on the Chicopee and at Cabotville, and an argillaceous limestone at West Springfield, that are pronounced by Prof. Hitchcock to furnish a cement as energetic as the "Roman." The following table contains their analysis:

Cement stone in Massachusetts.

TABLE II.

	Septaria from the Chicopee.	Septaria from Cabotville.	Argillaceous limestone, West Springfield.	
			1st Sample.	2d Sample.
Carbonate of lime.....	46.06	43.69	30.81	26.04
Carbonate of magnesia..	27.35	39.35	18.33	13.45
Silica and alumina.....	20.97	13.57	45.33	54.00
Oxide of Iron.....	5.62	3.39	5.53	6.51

The 2d sample from West Springfield is but feebly hydraulic.

23. East of Massachusetts, cement stone is found in some localities, but is not used for hydraulic mortar. Deposits exist at Machias and at the forks of the Kennebec River, Me.; a specimen from the last-named locality, analyzed several years ago by Dr. Charles T. Jackson, contained .54$\frac{4}{10}$ of carbonate of lime, .05 of carbonate of magnesia, .028 of carbonate of iron, .024 of silicate of iron and manganese, .27 of silica, .082 of alumina.

Cement stone in Maine.

24. Near Kensington, Conn., a good cement stone is found, which is manufactured to a limited extent for local use. In the West, supplies of this article are derived from Sandusky, Ohio, from Utica, Lasalle County, Illinois, and from near Louisville, Kentucky, at the Falls of the Ohio River.

Cement stone in Connecticut, Illinois, Kentucky, and Ohio.

25. The following extract from the forthcoming work of the State Geologist of Mississippi, gives the analysis of two cement stones found in that State in Tishamingo County: "No. 1 furnishes a cement which sets as rapidly as Plaster of Paris and becomes very hard. No. 2 differs from No. 1 in requiring more time to harden." See Table III.

Cement stone in Mississippi.

TABLE III.

	No. 1.	No. 2.
Silica and insoluble Silica.....	54.201	35.281
Potash.....	.473	.348
Lime.....	23.247	32.603
Magnesia.....	.788	.630
Protoxide of iron.....	.903	.158
Alumina.....	1.064	1.914
Phosphoric acid.....	Trace	
Carbonic acid.....	15.572	27.643
Water, organic matter, and loss.....	3.752	

26. No deposits of hydraulic lime or cement stone are found on the Pacific coast, although inquiries to a considerable extent have been made.

The Rosendale cements are depended upon for hydraulic mortar.

CHAPTER II.

27. The method pursued in testing the mortars which furnish the basis of all tables introduced into this report, with the exception of those compiled from the labors of others, for the purpose of reference and comparison, is briefly as follows:

28. With some exceptions that will be pointed out in the proper place, all the samples of hydraulic cement not prepared at the manufactories, under the personal supervision of the writer or an agent appointed by him, were obtained from cargoes in the market, by opening several casks selected at random, and taking two or three pounds from each. This precaution was adopted in order to secure, beyond a question, samples of an average quality from the respective cargoes, and for the time being, of the respective cements furnished by the several manufactories.

The cements not prepared under the writer's supervision were samples from cargoes in the market.

29. Identity in the composition and properties of samples of the same brand, obtained from different cargoes and at different times, was never assumed. An examination and comparison of the tables throughout this work, clearly establish the necessity of this precaution. As some manufacturers habitually grind their stone finer than others, and as there is considerable difference, in this particular, in cement from the same establishment manufactured at different times, due in part to the difficulty with which a high degree of pulverization can be secured with newly-dressed millstones, but principally to negligence on the part of the miller, it was important that this cause

of variation should be eliminated in all the trials, and particularly from those which were to furnish the data for a direct comparison of the qualities of the several cements, and of mortars of different composition, but particularly those containing large doses of sand. To this end, all the varieties of cement subjected to trial were passed through a fine wire sieve, designated No. 80, that is, containing eighty fine wires to the lineal inch, each way, or 6,400 meshes to the square inch. The sand used for the mortars, when the object was simply to compare the qualities of the several varieties of cementing substance, whether of pure cement, or a mixture of cement and lime, though quite fine, was clean, and tolerably sharp and angular. It is mostly silicious, and was obtained from a pit on Governor's Island, New York harbor, between Castle William and Fort Columbus. After being passed through a wire sieve No. 30, to remove a small per centage of gravel heterogeneously distributed through it, 1,000 parts by weight contained:

The cements were sifted in wire sieve No. 80.

Character of the sand used.

163 parts between $\frac{1}{30}$ and $\frac{1}{40}$ of an inch in diameter.
302 " " $\frac{1}{40}$ " $\frac{1}{60}$ " " " " "
352 " " $\frac{1}{60}$ " $\frac{1}{80}$ " " " " "
183 " less than $\frac{1}{80}$

CHARACTER OF THE TESTS APPLIED TO THE MORTARS.

30. 1st. *Their capacity to resist a transverse strain*, which is also a measure of their tenacity. To this end, rectangular prisms were formed in a cast-iron mould, under pressure or otherwise, as specially set forth in each particular case. The base of these prisms was two inches square, their height eight inches. The first that were prepared were formed in a horizontal mould, the pressure being applied to the upper side. As it was always necessary to shave off one of the sides of these blocks, in order to reduce the cross-section to a square, the horizontal mould was soon replaced by a vertical one, measuring

Mortars made in prisms 2 in. by 2 in. by 8, and broken on supports 4 in. apart.

2 in. by 2 in. by 8 in. in the interior, to one end of which the pressure was applied. When the prisms had attained the requisite age, they were broken on supports 4 in. apart, by a pressure applied at the middle point.

31. 2d. *Their relative hardness.*—This was measured by the penetration of a steel point or needle, impelled by the impact of a falling body. The needle, which is slightly conical, or tapering toward the point, is truncated at right angles to the axis, so as to give a diameter at the lower end of $\frac{1}{12}$ of an inch. It protrudes from a socket in the lower extremity of a vertical rod or spindle, to which it is firmly secured by means of a thumb-screw. To the upper extremity of the spindle is attached a diagonal scale of steel, accurately graduated to tenths, hundredths, and thousandths of an inch, and provided with a horizontal index firmly fixed to the frame-work of the instrument. The absolute pen-

Hardness compared by a needle penetrating by impact.

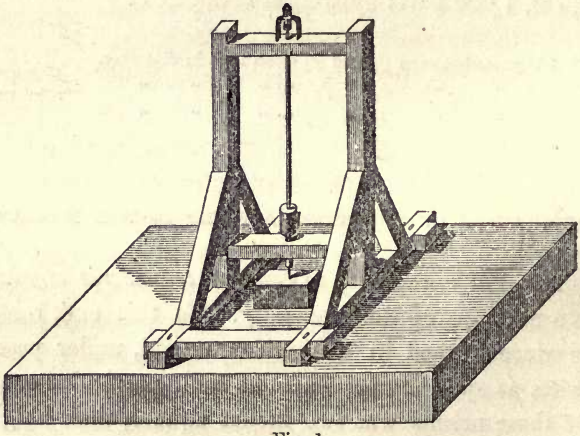


Fig. 1.

etration of the needle is obtained by taking the difference between the index readings before and after impact. The falling body is a hollow metal cylinder, weighing one pound, of which the exterior diameter is about equal to the length. This cylin

der, in its descent, passes freely over the spindle, and strikes upon a shoulder attached just above the screw. The mortar used to determine the hardness was that of the broken prisms, and the penetrations were taken the same day, generally but a few hours after they had been broken. As these fragments were 2 in. square in cross-section, and seldom less than 2½ in. long, they admitted of several trials with the needle. An average of not less than four penetrations, and sometimes more, at each end of the prisms, was taken on all occasions, except when the fragment split open at a lower number, which was sometimes the case. This instrument will be well understood by referring to Fig. 1.

32. 3d. *Their adhesive properties.*—This was measured by cementing bricks and blocks of stone together in pairs, and afterwards drawing them apart by a force applied at right angles to the plane of the joint. The bricks or stone of each pair were arranged at right angles to each other, as seen in Fig. 2, and were kept together under a pressure of 500 lbs., except on occasions specially mentioned, until the mortar had set.

Adhesiveness to brick or stone measured.

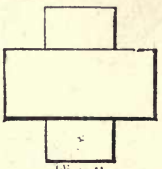


Fig. 2.

33. *The device for applying the pressure to the prisms*, and to the pairs of bricks or stone, while the mortar was setting, is essentially the same as that heretofore used for similar purposes. It was also used for testing the strength and adhesiveness of the mortars, when they had attained the proper age. The apparatus consists essentially of a bed-piece and two upright posts, about one foot apart, connected by a cross-piece at the top, from the centre of which is suspended a scale-beam, so arranged that it can be elevated or depressed, as occasion may require, by means of a screw. The lower hook of this beam is connected with a horizontal lever of equal arms, so that any weight indicated by the beam will be transmitted without loss to the reverse end of the lever, and will then act

Device for compressing the green mortars into moulds, breaking the prisms, &c.

as a downward pressure. The application of this pressure to the breaking of prisms is explained by Fig. 3. It is only necessary to replace the wedge-shaped piece which acts upon the prisms by another which will diffuse the pressure over a horizontal area of greater or less extent—say about one superficial inch—in order to adjust the instrument for applying pressure to the mortar in the moulds, and to the pairs of bricks or stone. Fig. 4 represents a prism under pressure. The lower

Fig. 4. Fig. 5.

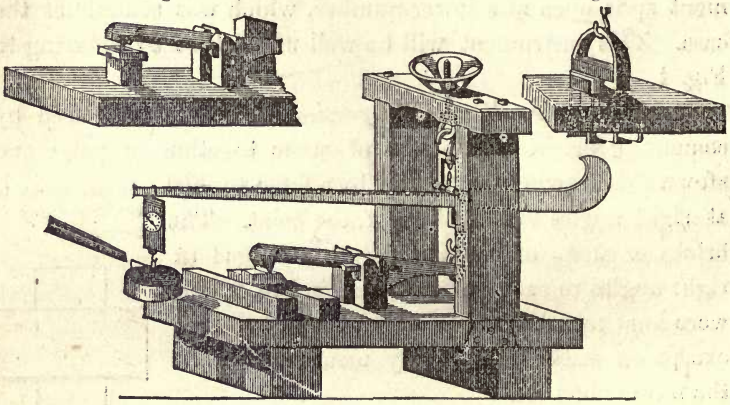


Fig. 3.

portion of the mould is inserted into a mortise in the bed-plate. In order to measure the force necessary to separate the bricks or stones, they are placed directly under the hooks of the scale-beam, the lower lever having first been removed. The lower brick or stone is then confined to the bed-pieces by staples, keyed from below, while the upper one is embraced by the ends of a crescent-shaped iron, suspended from the hook of the scale-beam, as shown in Fig. 5.

34. In all cases, the moment of rupture was attained as quickly as possible—care being taken to avoid shocks—by pouring sand into the pan of a spring-balance suspended from some given point on the beam, as shown in Fig. 3. In setting forth the results

Instant of rupture to be attained quickly.

of these trials in a tabulated form, the actual breaking weight and penetration are, in all cases, entered without reduction except in the case of separating the bricks and stone, when an additional column is inserted in some cases, giving the adhesive power per superficial inch.

35. The trial with the needle was adopted as the most ready means of measuring the relative hardness of the several mixtures containing no sand, whether of pure cement or a combination of cement with fat lime. Nothing further than this was at first expected from it. M. Vicat at one time entertained the opinion, which he subsequently qualified and even abandoned, that "the squares of the numbers which express the penetration of the rod are reciprocally proportional to the resistances to the force which tends to break the mortars." General Treussart not only doubts the existence of this law, as not fully established by M. Vicat's experiments, but advances objections to the use of the needle, which do not appear to be wholly tenable, viz:

Why the test with needle was adopted.

Law deduced by Vicat; abandoned by him.

1st. That it is difficult to appreciate exactly its penetration;

2d. That, if it falls upon a grain of sand or gravel, or even a grain of lime, incorrect conclusions will be drawn;

3d. That it is applied to the surface of the mortar, which frequently differs in hardness from the interior.

General Treussart's objections to the *needle* test.

36. It is submitted that the first of these objections cannot apply to an instrument like that shown in Fig. 1, if constructed with accuracy and used with care; the second is equally without force when no sand is introduced into the mixtures; and even the effect of sand of fine grains, in large doses, might be regarded as practically inappreciable, provided the weight of the falling body and the distance passed over in the descent are such as to cause

The first not tenable when needle is used with care.

The second ditto, for mortars without sand, or under heavy impacts.

deep penetrations. Moreover, an ordinary degree of precaution would suggest the propriety of taking the average of a large number of trials in preference to the results indicated by a single one, when they can be repeated with such ease and rapidity. It is not contended that penetrations from impact afford reliable data for comparing mortars containing different proportions of sand, or sand in different degrees of fineness. The objection urged against deducing conclusions with regard to the quality of a mass of mortar from the results of trials restricted to its surface, is certainly worthy of consideration when mortars of common lime, either with or without sand, are under trial, but is scarcely applicable to hydraulic mixtures. The absolute strength of a mass of mortar is not the only good quality we seek. Deterioration from the action of the elements first takes place upon the surface in all cases, and it is upon the surface, without regard to interior qualities, that the requisite power of resistance against these agents must be conferred. Experience teaches us that those mortars which attain the greatest degree of superficial hardness, as shown by the penetrations of the needle, absorb the least amount of water, and are consequently the least liable to undergo disintegrations from frost or "weathering." The resistance offered at the surface to the penetration of a point acted upon by an impulsive force, therefore, affords reliable means of judging of a most important property in mortars, even if we admit that our conclusions must necessarily be restricted to their surface. But this is not so. It is well known that hydraulic mixtures owe very little of their powers of sub-aqueous induration to the absorption of carbonic acid gas, or to superficial desiccation; that the setting is not initiated at the surface, but almost simultaneously throughout the mass; and that the subsequent induration is not augmented, but rather retarded, and in some measure even destroyed, by free contact with the air, and the absence of humidity.

Remarks on third objection.

Cement mortars harden simultaneously throughout the mass.

37. We may safely assume that mortars of hydraulic cement, either with or without sand, if submerged, harden so nearly homogeneously throughout their entire thickness, that there is no perceptible difference in hardness at the centre, and at a depth of $\frac{1}{10}$ to $\frac{1}{8}$ of an inch. At any rate, those disposed to entertain doubts upon this point can readily convince themselves, by reference to the tables, that, with individual exceptions, the mortars which sustain the greatest transverse strain give the smallest penetrations with the needle; and it certainly is not unreasonable to suppose that there may exist a fixed law or proportion between the resistances offered to two kinds of forces, —one constant, and the other impulsive,—by an inflexible substance like mortar.

The strongest prisms gave the least penetrations.

CHAPTER III.

38. The celebrated Rosendale cements,—so named from the fact that the stone was first discovered in the township of Rosendale, Ulster County, New York, in opening the line of the Delaware and Hudson Canal—are derived from the tentaculate or water limestone belonging to the lower Helderberg Group, known as Formation VI. in Professor H. D. Rogers' classification of the rocks of Pennsylvania. As stated in Chapter I., the deposits are mostly found within the limits of a narrow belt scarcely one mile in width, skirting the northwestern base of the Shawangunk Mountains, along the line of the Delaware and Hudson Canal, in the valley of Rondout Creek. The beds are found occupying every conceivable inclination to the horizon, being sometimes vertical, seldom on a level, and ordinarily dipping at a greater or less degree either to the northwest or to the southeast. The entire face of the country in this region exhibits unmistakable evidences of having been subjected to a succession of remarkable upheavings; some of them have evidently taken place while the limestone deposits were as yet in a plastic form, by which the strata, in many localities, were twisted into a variety of complex and tortuous shapes, while others, transpiring at subsequent periods more or less remote, have ruptured the beds in a variety of ways, frequently producing faults, but ordinarily resulting in a multitude of seams more or less open, running diagonally across the planes of stratification. The

The "Rosendale" Cement.

Geographical limits of the beds now worked.

The beds are tortuous.

useful effect of these upheavings has been to develop, into accessible and convenient positions, a vast amount of cement stone, that would otherwise have been buried beyond the practicable reach of ordinary mechanical skill.

39. The aggregate thickness of the several layers of this deposit averages about forty-six feet. This includes several strata, varying from four to twelve feet in total thickness, which are so changeable in character that they are fit for use only in certain localities. The whole deposit is subdivided into several distinct layers, which are widely dissimilar, as a general thing, in the color, grain, and texture of the raw stone, and also in their hydraulic properties after calcination. As many as seventeen of these layers can be traced throughout the entire range in Ulster county.

Aggregate thickness of the several layers.

Seventeen layers in all.

40. No one manufacturer makes use of all of these beds, and no two of them of the same beds, in the same proportions. This is due, principally, to those marked variations in the hydraulic character of the stone, within comparatively short distances, which constitute a characteristic feature of this deposit, already referred to in general terms.

Not all used for cement: due to the changeable character of stone.

41. In some localities, the upper layers of the cement bearing series have been removed by abrasion, while in others, the lower ones have been thrust so much out of place by the interposition of other rocks, or are so far below the general surface level, that they cannot be reached with facility or economy.

Upper layers sometimes absent, and lower ones beyond reach.

42. Few of the manufacturers have rendered themselves familiar with the distinctive and peculiar properties of the several layers which they introduce into their combination, instances being comparatively rare where they have caused them to be quarried, calcined, and ground separately, even for the purpose of experiment.

43. With few exceptions, all the stone taken from a quarry

enters into the cement prepared for market. This includes certain layers, or portions of layers, possessing little or no hydraulic energy by themselves, on account of the preponderance of inert silica or alumina which they contain, and the absence of homogeneousness in the composition; other portions, in which the carbonate of lime is largely in excess, and which may be classed among ordinary hydraulic limes; and still others, which are an exaggerated type of the dividing limes (*chaux limites*) of Vicat, setting rapidly in water under the most difficult circumstances, succedeed sooner or later by a gradual softening of the whole mass.

Some inferior stone is used.

44. Although mortars giving rise to the phenomena last-mentioned contain an excess of caustic lime, which becomes hydrated very sluggishly, and indeed not until the hydraulic induration has fully commenced, and which, therefore, is insusceptible of prompt neutralization by the silica, alumina, and magnesia present, in the formation of those treble hydrosilicates that are practically insoluble in water, it does not necessarily follow that their incorporation in subordinate proportions, and under judicious restrictions, into the aggregate product of a quarry, is injurious. In certain cases, when care is taken to reduce the cement to a very fine powder, with a view to facilitate the hydration of the lime, and to secure a thorough incorporation of the several kinds of stone used, they are believed to operate beneficially by furnishing those requisite constituent ingredients of good cement not found in sufficient quantity in the contiguous rocks,

Stone individually bad, not necessarily objectionable in a combination.

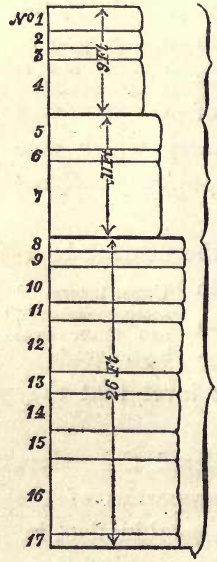


Fig. 6.

or existing there in proportions capable of considerable increase, without producing an injurious excess.

Section of the cement deposits of Ulster Co., N.Y.

The marginal sketch, Figure 6, shows an actual section of these deposits, verified in several localities, where the layers occur in regular order.*

45. In some localities, where the beds have been upheaved into a vertical position, or nearly so, and the stone of inferior quality occurs in layers of sufficient thickness to sustain themselves, they are left intact, supported at appropriate intervals by masses of the stone composing the adjacent layers.

46. Some of the most prominent features of these several layers will now be briefly noticed. They were quarried and calcined separately by an experienced workman. For their burning, "*try-kilns*" 7 to 7½ feet high and 20 to 24 inches in interior diameter were used, and the object aimed at in each case was to submit every variety of stone to that degree and duration of heat that would produce the best results. Besides these tests, others were made with the stone by submitting it to different degrees of calcination in crucibles.

47. *Number One* is moderately fine grained, of a dark gray color, and contains rather too much silica. After burning, the cement is of a light-drab color, and sets under water in fifteen

* The sections of the cement strata in Ulster County, as given in the Report of the State Geological Survey, are singularly at fault. The one purporting to have been taken at High Falls, near and just below the bridges (see Report of First District State Geological Survey, p. 353), is as follows:

Cement rock	12 to 15 feet
Limestone	10 to 30 "
Cement rock	6 to 8 "
Pyritous slaty limestone	4 to 10 "
Red shale, &c	15 to 20 "
Conglomerate and Shawangunk grits	unknown thickness.

The correct section of the beds in this locality, now constituting Ogden & Co.'s quarry, and at the time of the survey owned and worked by Mr. J. L. Hasbrook, is as follows:—the layers above No. 9 do not occur here.

Cement rock	15 to 16 feet.
Magnesian limestone, unsuitable for cement, and therefore not used. It is dividing lime	2 to 2½ "
Cement rock	5 to 6 "
Argillaceous slaty limestone	½ to 1 "
Pyritous limestone, Shale, &c., as before	}

Number One a good stone, except at Lawrenceville.

minutes to bear the light testing-wire.* This stone, except in the vicinity of Lawrenceville, where it possesses, to a limited extent, the objectionable properties of intermediate limes, furnishes a good cement by itself.

48. *Number Two* resembles the preceding, when in the raw state, but is of a somewhat darker color, and is much quicker setting after calcination. In the vicinity of Lawrenceville it possesses, to a limited extent, the bad qualities of the "intermediate" limes, and is unfit for use, except in combination with the other layers. It is not excluded by any of the manufacturers.

Number Two resembles Number One.

49. *Number Three* is a coarse-grained light-gray magnesian limestone, containing, after calcination, an excess of caustic lime and silica in the form of sand. It belongs to the worst type of intermediate limes, and is incapable of being used alone, except after several months' exposure to the effects of air and moisture, either in casks or in bulks, and even then is greatly improved by being mixed with ten to fifteen per cent. of an active cement, with a view to restore the energy destroyed during the process of spontaneous slaking. A fresh sample, mixed to a stiff paste, and formed into a cake, set in the air in eight minutes, and was then immersed in water at 65° F. It soon began to soften, and in one hour allowed the light-testing wire to pass freely through it. Another cake, immersed in water in the condition of paste, began to set in four or five minutes, so far as to lose the plastic form, which was immediately followed by the appearance of a multitude of small cracks, and a rapid and progressive softening from the surface inwards. After fifteen minutes it was worked up under the trowel, dried off with blotting-paper to a stiff paste, again formed into a cake, and immersed. At the expiration of twenty

Number Three is an "intermediate lime."

Sets in the air quickly, but softens when put in water.

*For a description of the testing-wire, see paragraph 121.

minutes, a close network of cracks again covered the surface, when it was worked up, as before, for the second time. This operation was repeated for the third and fourth times before the submerged cake would retain its form under water, and indurate without cracking. It then required six days to bear the $\frac{1}{24}$ inch wire, loaded to one pound. Some of the powdered cement was heated to redness for half an hour, in order to approximate more nearly to the condition of complete calcination, but its qualities were in no respect improved thereby. Some of the same cement, when fourteen months old, after having been preserved in an ordinary powder-keg, without paper lining, during that period, had entirely lost the dangerous property of disintegrating under water, which it possessed in such an eminent degree when fresh. It had also parted with much of its hydraulic energy, requiring from eight to nine hours, when submerged, to attain the requisite hardness to support the light-testing wire, and twenty hours to support the heavy one. Some of this old cement was heated to redness for half an hour, which, while it fully restored its hydraulic activity, at the same time destroyed its ability to stand up under water.

Trials were also made by adding to this cement a soluble alkaline silicate, in order that silica might be presented to the lime in a condition favorable to an immediate combination with it, with a view to anticipate, as it were, the initial induration of the native hydraulic ingredients. The results were entirely satisfactory. The double silicate of potash and soda was employed for this purpose, in the successive proportions of 11, 9 and $5\frac{1}{3}$ per cent., by mixing it with the water used for bringing the cement to the condition of paste. In the first two cases the success appeared to be perfect, and resulted in the cakes setting under water in ten minutes to bear the light testing-wire, and in twenty-five and thirty minutes respectively to bear the heavy one, without any subsequent appearance of cracks or change of form. With $5\frac{1}{3}$ per cent. of the alkaline

Trials with "soluble glass."

Eleven per cent. of same makes Number Three a good cement.

silicate, the cracks upon the surface were not entirely avoided, but they penetrated but a very little way into the mortar, caused no visible change of form, and appeared to exercise no influence upon its ultimate strength and hardness.

Number Four subdivided into two layers.

50. *Number Four*, in some localities, is solid and compact throughout, and in others is subdivided into two layers of nearly equal thickness. The upper portion is fine grained, dark blue, burns of a light drab color, and is quick setting; that below is darker after calcination, contains more lime, and does not set readily under water, if immersed in the state of paste. Between these two subordinate members of this layer, a thin sheet of argillo-calcareous slate sometimes occurs, which has to be excluded from the combination. With this exception, the entire layer, worked together, makes a cement of fair average quality, and there is perhaps no member of the deposit in Ulster Co. which preserves, throughout its entire development, a character more uniformly reliable. Immersed in the state of paste, in water at 65° F., it hardens so as to support the light testing-wire in fifteen to twenty minutes, and the heavy one in twenty-five to thirty minutes.

The entire layer makes good cement.

51. *Number Five.* This layer, throughout the entire range of the beds as yet opened, except in the quarries belonging to the Newark Lime and Cement Manufacturing Company, at the mouth of the Rondout Creek, is a coarse-grained magnesian limestone, containing so large an excess of carbonate of lime that it generally slakes after calcination, like hydraulic or meagre lime. In the quarries of the Hudson River Company, about five miles back from the Hudson, the upper half of the layer is more highly charged with clay and magnesia, and is so far modified in its prevailing character that it is included in the combination. With these two exceptions, the stone is rejected by manufacturers.

Number Five slakes after calcination, like meagre lime, and is generally rejected.

52. *Number Six* is a limestone of slaty structure, containing

a large amount of clay and lime, particularly of the latter, and possessing, to a certain extent, the objectionable properties of Number Three. It varies in thickness from six inches to two feet, and possesses a distinct development in all the quarries, except those at the mouth of the Rondout Creek, where it has either been omitted in the deposition, or has been more or less uniformly distributed through out the contiguous layers. The latter would appear to be the most probable hypothesis, as those layers (Five and Seven) which in most of the quarries contain a ruinous excess of carbonate of lime, constitute in this locality the best stone of the deposit. When made into cement, and allowed to *set* in the air, the influence of water upon it after immersion is moderately slow, so that the mortar is not thrown down completely, like that derived from Number Three, but is simply covered with many deep cracks. A prism measuring 2 in. × 2 in. × 7 in. was formed of a paste of the pure cement from this layer, as developed at High Falls, and immersed in water after supporting in twenty minutes the light testing-wire in the air. After twenty hours, it began to swell and crack along the longest edges, the cracks being directed toward the axis. After thirty hours, these cracks presented an exterior opening of $\frac{1}{8}$, and after fifty hours, of $\frac{1}{4}$ of an inch. The prism then broke into three pieces transversely, and was nearly a week in assuming a stable form. The form of a cross section at that time is shown in Fig. 7.

Number Six is an intermediate lime.

Prism of pure cement from this layer.

Fig. 7.

53. *Number Seven* is perhaps the most changeable member of the cement deposit. Near High Falls, on Coxon Cove Creek, it was manufactured into a cement several years ago by Mr. O'Neill, which was considered by the late Col. J. L. Smith, of the Corps of Engineers, superior to any cement brought into market at that time. In other localities, near High Falls, the stone is

Changeable character of Number Seven.—The O'Neill cement.

in every respect as good as that used by O'Neill, but all attempts to turn it to any account elsewhere have failed, except at a point above one mile south of Rosendale Village, where it was worked in 1840, and at the mouth of Rondout Creek, twelve miles distant, where it is of good quality, and furnishes about 25 per cent. of all the stone used in that neighborhood. In connection with the two overlying strata, Five and Six, it constitutes the middle rock, a prominent feature, common to all parts of the range (with the exceptions mentioned above) which is not disturbed in quarrying. The prevailing character of Number Seven, to which its bad qualities are chiefly due, is its remarkable and persistent want of homogeneousness. When burnt, it presents an entire absence of any uniformity of color, being generally variegated and mottled in appearance, exhibiting almost every grade of neutral tint between pure white, derived from masses of carbonate of lime, and the darkest brown, approaching to black. Hence the constituent elements of the stone, although they may be present in suitable proportions, are beyond the influence of those mutual reactions which take place during the calcination, when the ingredients are in intimate and homogeneous contact, and the lime which should have entered into combination with the silica remains free and in excess. Instead of being pure, however, or practically so, a condition which would be favorable to its instantaneous slaking when brought into contact with water, it is mixed with a sufficiency of foreign matter to render it meagre, technically so called, and consequently sluggish and tardy in assuming the form of hydrate. Number Seven is therefore, with the exceptions noted, an intermediate lime, and unfit for cement.

Number Seven, not generally good.

Is generally left undisturbed in the quarry.

54. *Number Eight* is unsuitable for cement in any part of the range yet opened. It is much more uniform in appearance, and is far less heterogeneous in composition, than Number Seven. In the vicinity of High Falls,

Number Eight is unsuitable for cement.

it is characterized by the objectionable properties of Number Three. It will commence to set readily under water, but in a few hours becomes converted into a thin paste. Further east, it loses all power of indurating under water, and will not retain in that situation a *set* taken in the air. In some localities it adheres to, or rather forms a part of Number Seven, and is left standing with it, while the underlying and overlying strata are removed; in others it becomes separated in blasting, and in many cases, it is feared, finds its way into the manufactured cement, and injures its quality.

Will not set under water

55. The layers numbered from *Nine* to *Sixteen*, inclusive, possess no striking individual characteristics, except in two localities. Taken together in the proportion of their development in the beds, they furnish a cement of good quality. Its hydraulic activity is somewhat less than that derived from a combination of the "Upper Series" of layers exclusively, but, in ultimate strength and hardness, it will compare favorably with any cements in the country. The two exceptions are as follows, viz.: one at High Falls, where Number Fifteen is an intermediate lime like Number Three, while Number Sixteen sets more rapidly under water than any strata in Ulster Co.; and the other at the mouth of Rondout Creek, where the "Lower Series" of strata do not occur at all, or are so changeable in hydraulic character, chemical composition, and lithological features, that their geological identity is a matter of some doubt.

Layers Number Nine to Sixteen do not differ strikingly.

Number Fifteen at High Falls is an intermediate lime, and Number Sixteen very quick setting.

56. *Number Seventeen*, although differing very materially from Number Sixteen after calcination, is mechanically attached to it, and has generally to be taken out with it. It contains a very large proportion of refractory clay, and is in most localities, and particularly at High Falls, very hard, like overburnt bricks, when cal-

Number Seventeen not a good stone.

cined in the same kiln with the other layers. It possesses little hydraulic energy, and should be excluded from the combination. As a prominent feature of the entire deposit, the color of the burnt stone is subject to great changes, within short distances.

57. At High Falls, the southwestern terminus of the deposit as now worked, where the manufactories of the Ogden Company, and Delafield & Baxter (formerly Ogden & Delafield) are located, all the layers, and consequently combinations of them adopted for the articles sent to market, are lighter colored after burning than in any other locality. As we approach the Hudson River the "Lower Series" undergo a decided and sudden change, so much so, indeed, that at Lawrenceville, only two and a half miles from High Falls, although they furnish but .60 of the combination used by the Lawrence Company, and although one-half of the remainder is brought from High Falls, and is very light-colored, the combination is one of the darkest of the Rosendale brands. Between this point and the Hudson, their color remains dark, and that of the "Upper Series" becomes moderately so. In point of fact, the only Rosendale cements technically termed "*light*" are the two brands manufactured at High Falls by Delafield & Baxter, and the Ogden Cement Company.

The cement made at High Falls is light colored, becomes darker as we approach the Hudson River.

58. The *Newark Lime and Cement Manufacturing Company* is located on the Hudson River, at the mouth of Rondout Creek. Its works comprise seventeen cylindrical kilns of the pattern shown in Figure 12, and the mill driven by steam-power, containing five "crackers" and eleven run of stone of two and a half feet in diameter, and two run of four and a half feet diameter. Four of the crackers, and five run of stone, can grind eight hundred barrels of cement per day. The cement stone occurs in a continuous bed varying in thickness from twenty to thirty feet, and dipping to the northwest

Newark Lime and Cement Manufacturing Company.—Capacity of their works.

from 45° to 75°. It crops out along the eastern slope of a high hill or bluff, at an elevation, in places, of from 150 to 170 feet above the level of the Hudson River. This deposit is reached by five horizontal tunnels, which pierce the slope of the hill near its base at five different points, by means of which the quarried stone is conveyed to the kilns by cars. There is a marked difference in the qualities of the stone in these several quarries, as well as among the several layers of the same quarry, and great care is exercised in distributing the aggregate yield of the entire deposit among the several kilns, in order to secure as great a degree of uniformity in the quality of the cement as possible.

59. None of the Lower Series of cement strata (see paragraph 44) are used by this company. The upper layers, from Number One to Number Three inclusive, are in some places too highly charged with carbonate of lime to admit of their entering into the combination. No attempt, however, is made (and it probably would not be advisable) to exclude any layer entirely, the skill and experience of the workmen being, in a great measure, depended upon to detect and throw out those portions of the stone which might injure the quality of the cement. These generally occur in patches, varying from a few inches to several feet in length and breadth, which are recognized by their coarse-grained or crystalline appearance, or some other characteristic feature. With the exception of these rejected portions, all the layers from Number One to Number Seven, inclusive, enter into the cement in the proportion of their thickness in the deposit.

"Lower Series" not used by this company

This company has a branch at Newark, New Jersey, to which place the stone is conveyed in the raw state.

60. *The Lawrence Cement Company*, manufacturing the "Hoffmann" brand, have their quarries and kilns above Whiteport, about seven miles back from Rondout. Their mill, driven by steam-power, is located on

The Lawrence Cement Company.

the left bank of the Rondout Creek, about two and a half miles from its mouth, and below the slack water of the Delaware and Hudson Canal. They have twelve kilns of the old pattern (Figure 12), four run of stone two and a half feet in diameter, and two crackers.

Their combination comprises stone from three quarries, as follows: the first, eighteen feet in thickness, comprising the layers from Nine to Sixteen, inclusive; the second, eight to ten feet in thickness, containing Number One to Four, inclusive, rejecting Number Three, separated from the first by the "Middle Rock;" and the third, ten to eleven feet in thickness, comprising the same strata as the latter (One to Four, rejecting Number Three).

After calcination, the stone is carried in wagons to the mill, four miles distant, and is then mixed together in the proportion of

13½ per cent of the first quarry (Numbers Nine to Sixteen).
26⅔ " " " second quarry (Number One to Four, rejecting Number Three).
60 " " " third quarry (" " " " " ").

61. *The Newark and Rosendale Company* have all their works at Whiteport, six miles from Rondout, and about three miles from the point of delivery to boats below the locks of the canal. They have fifteen kilns of the old pattern (Figure 12), and one of Page's Patent (Figures 13 to 18). Their grinding apparatus comprises three crackers and four run of five feet stone, driven by steam, and one cracker and three run of four and a half feet stone, driven by water. Their quarries are in the immediate vicinity of those belonging to the Lawrence Company, noticed above, and they make use of the same kind of stone, but combined in different proportions. They have, from time to time, derived their stone from eight different openings, but, at the present time, work three principally. Two of these are parallel to each other, comprising respectively the Upper and the Lower Series of layers, separated by the Middle Rock,

The Newark and Rosendale Company.

which is worthless in this locality; the third furnishes the Upper strata only, One to Four, inclusive. Their combination is as follows:

50 of the Upper Layers (One to Four) from two quarries, rejecting part of No. Three.
50 of the Lower Layers (Nine to Sixteen).

62. *The Rosendale Cement Company*, manufacturing the "Lawrence" brand, is located at Lawrenceville, on the line of the Delaware and Hudson Canal, six and a half miles from Rondout. They have seven kilns of the old pattern (Fig. 12), and four run of stone, four feet nine inches in diameter. They grind by water power. The stone is procured from three quarries, as follows. The Rosendale Cement Company.

The *first* is near High Falls, two miles above Lawrenceville, and furnishes the Upper Layers (One to Four, inclusive), of which a large proportion of Number Three is rejected. This stone, after burning, is conveyed by land carriage to the mill at Lawrenceville.

The *second* quarry is situated on the east side of Rondout Creek, at Lawrenceville, and furnishes the Lower Layers (Nine to Sixteen, inclusive).

The *third* is about a quarter of a mile distant from the latter, on the west side of the creek, and contains the layers One to Four, inclusive, of which Number Three is rejected. This last-mentioned bed overlies in regular order the Middle and Lower Series. Numbers Nine to Sixteen were formerly quarried at this point, and included in the combination, but for some years past have been omitted, on account of the alleged presence of an excess of carbonate of lime, an objection which is presumed to be more imaginary than real, as the strata, having been treated separately with great care, gave results which compared favorably with those obtained from the corresponding layers on the opposite side of the creek.

The stone from each quarry, after being burned separately, is added to the combination in grinding in the following proportions, viz.:

.20 of the first, One to Four, inclusive, rejecting most of No. Three.
.60 " second, Nine to Sixteen, inclusive.
.20 " third, One to Four, inclusive, rejecting No. Three.

63. *Delafield & Baxter*, formerly Ogden & Delafield, are located at the High Falls of Rondout Creek, twelve miles from its mouth, on the Delaware and Hudson Canal. Their mill is driven by water-power, and consists of three crackers, and four run of four and a half feet stone. They have six kilns of the usual form (Fig. 12).

Delafield & Baxter.

Three quarries furnish the stone used in the combination. The first comprises the layers from Nine to Sixteen, inclusive, of which parts of Thirteen and Fifteen are too highly charged with carbonate of lime, and have to be rejected; the second comprises the Upper Strata, One to Four, inclusive, of which portions of Number Three are excluded. These two quarries are located near each other; the third is about half a mile distant, and contains Number Sixteen only, which occurs in a partially disintegrated or slaty form, and is therefore known as the "Slate Quarry." In the combination, the products of these three quarries are mixed together in equal proportions, viz.:

33⅓ of Nine to Sixteen, inclusive, rejecting portions of Thirteen and Fifteen.
33⅓ of One to Four, " " " No. Three.
33⅓ of No. Sixteen.

Layer Number Sixteen in this locality possesses remarkably quick setting properties. It will harden under water more rapidly than any cement in Ulster County, and is added to the combination with a view simply to increase its hydraulic activity and energy. Delafield & Baxter are also the proprietors of the quarry which some years ago furnished the O'Neill cement, an article which sustained a high reputation among military engineers. It comprises the middle layers Six and Seven. It is not worked at the present time, but will probably, at no distant period, have to replace their "Slate Quarry" in the combination, as the latter is becoming exhausted.

Layer Number Sixteen very quick setting.

64. *The Ogden Rosendale Cement Company* is also located at High Falls, near Delafield & Baxter's. Their mill is driven by water-power of great capacity, and contains two crackers and four run of four and a half feet stone; their kilns, at present four in number, are of the old pattern (Fig. 12). The stone is derived from an opening contiguous to Delafield & Baxter's "Slate quarry," and comprises the Lower Series of layers Nine to Sixteen, inclusive, rejecting Number Fifteen on account of the large excess of carbonate of lime which it contains, and which places it among the intermediate limes. Layers Nine to Thirteen are subject to frequent and peculiar variations in hydraulic energy, containing in places so large an excess of caustic lime after calcination, as to render it necessary to reject these portions when detected.

The Ogden Rosendale Cement Company.

The combination adopted by this company is varied from time to time, as circumstances require, Number Sixteen being principally depended upon to compensate for any deficiency in hydraulic activity in the superincumbent layers. The usual proportion is:

50 of layers Nine to Fourteen, inclusive, rejecting parts of Nine and Thirteen.
50 " No. Sixteen.

The color is light, like that of Delafield & Baxter. Layer Number Sixteen of Ogden's quarry appears to possess all the distinct and characteristic properties of Delafield & Baxter's "Slate" quarry, that is, it has a slaty structure, burns light colored, and is remarkably quick setting under water. It is a noticeable fact, that, in this particular spot, this stratum, although distant but 400 or 500 yards from the other quarries in the neighborhood, possesses local properties so peculiar, that it would be difficult, in the absence of the most direct and palpable evidence of their geological identity, to believe them to be parts of the same layer. It is only at High Falls, and apparently within contracted limits even there—possibly not more than two to three hundred

Layer Number Sixteen.

yards in extent—that it possesses any superior hydraulic activity. As we descend the valley of the Rondout, it burns dark colored, and becomes comparatively slow setting.

65. At Bruceville, half to three-quarters of a mile below High Falls, Mr. *N. Bruce* manufactures cement from the Lower Layers, Nine to Sixteen, inclusive, to which is added a stratum about eighteen inches thick, situated twelve feet below Number Sixteen, and separated from it by a conformable bed of argillaceous shale. It is not certain whether this stratum forms a part of the cement bed as described, or is a separate and independent deposit, formed out of its usual position by the local intervention of the shale. This cement is light colored, like Delafield & Baxter's. Mr. Bruce also works the Lower Layers at the Green kilns, five miles from Rondout, near the line of the Delaware and Hudson Canal.

66. *Martin & Clearwater* have their works on the line of the Delaware and Hudson Canal, seven and a half miles from Rondout. This mill, comprising four run of four feet eight inches stone, and the requisite number of crackers, is driven by steam-power. They have six kilns of the old pattern. (Figure 12). Their stone is derived from two parallel beds comprising the Upper and the Lower Series of strata respectively, separated by the Middle Rock, Numbers Five, Six, and Seven, which is here entirely unfit for cement. Their combination is as follows:

Martin & Clearwater's.

.50 of the layers One to Four, inclusive; rejecting portions of Three and Four.
.50 " " Nine to Sixteen, inclusive.

67. The quarries of *The Hudson River Cement Company* are situated about one and a half miles from the Delaware and Hudson Canal, five miles from Rondout. Their mill, comprising four run of four and a half feet, and two run of two and a half feet stone, as well as their kilns, are in Jersey city. Their combination comprises equal proportions of the stone from the Upper and from the Lower Layers, including about one half of Number Five, and differs

The Hudson River Company.

from all others into which the Lower Layers enter at all, in including the whole of Number Three. It is therefore as follows:

.50 of layers One to Four, inclusive, and one-half of Number Five.
.50 " Nine to Sixteen, inclusive.

68. *Maguire, Crane & Co.* have recently commenced manufacturing cement near Martin & Clearwater. Their quarries join each other, and are, in every respect, alike in the character of the stone and the number and thickness of the strata. Their mill is driven by steam-power, and contains four run of four and a half feet stone. Four cylindrical kilns of the old pattern (Figure 12) are used in burning the stone. Maguire, Crane & Co.

69. *The Lawrenceville Cement Manufacturing Company* is located at Lawrenceville. Their milling apparatus comprises six run of four and a half feet stone, four of them driven by steam-power of ample capacity, and two by water-power, provided with the requisite number of crackers. Their stone is derived principally from the Lower Series of layers. A portion of Number Seven, which is divided into three layers possessing very different qualities, is also added to the combination. This quarry is but two or three hundred yards distant from the one worked by the Rosendale Cement Company, on the west side of the Rondout Creek, in which the Lower Layers have been regarded—with insufficient cause, it is thought—as too highly charged with carbonate of lime. The Lawrenceville Cement Manufacturing Company.

70. *The Rosendale and Kingston Cement Company* are located at Flatbush, on the right bank of the Hudson River, about three miles above Rondout. Their mill is worked by steam-power, and contains four run of four and a half feet stone. Their stone is burned in the old-fashioned kilns (Figure 12), and is derived in part from quarries situated about 300 yards from the mill, which furnish the layers Three and Four of the Upper Series, and Nine to Sixteen, inclusive, of the

The Rosendale and Kingston Cement Company.

Lower Series; and in part from an opening in the Lower Layers on the line of the Canal, near Martin & Clearwater's works. This stone is transported in the raw state to the kilns, which are located near the mill. Their combination is as follows:

.33⅓ of layers Three and Four, at Flatbush.
.33⅓ " Nine to Sixteen, inclusive, at Flatbush.
.33⅓ " " " from near Martin & Clearwater's, ten miles distant.

71. Hydraulic cement is manufactured on the Potomac River, which finds its way to an eastern market, viâ the Chesapeake and Ohio Canal. There are three works, located respectively at Shepherdstown, Va., at Hancock, Md., and at Cumberland, Md.

72. *The Shepherdstown Works* comprise two run of four and a half French burr stones and the necessary crackers, driven by water-power, and three perpetual kilns of the form given in Figure 11. Cumberland coal is used for burning. The stone is derived from deposits which crop out in several places on the banks of the Potomac, near the mill. Though considerably tortuous and irregular, their general position is nearly vertical. The stone is quarried from the top of the hill, is then passed into the kilns, situated on the slope below, and subsequently to flat-boats in the mill-race. These are then floated into the mill, and the burnt stone is discharged through hatchways up to the crackers.

Cement Works at Shepherdstown, Va.

73. The deposit is in two principal layers, one of which furnishes a *quick*, and the other a *slow* setting cement. The two are mixed together in nearly equal proportions, a combination which is believed to yield a better cement than either of the beds would if used alone.

The deposit in two layers, one *quick*, and the other *slow* setting.

74. Besides the quarry from which the stone is at present derived, there are several outlying cement strata, or perhaps

other outcrops of the same strata, near by, intermixed with layers of nearly pure limestone, which were added to the combination in former years; but the extra expense arising from the necessity of quarrying out the common limestone in connection with them, and the doubt as to their possessing any superior qualities, led to their final exclusion.

It is impossible to estimate satisfactorily the extent and capacity of these quarries, and it is believed that no critical examination by experienced geologists has ever been made with that end in view. The peculiar position of the beds would lead to the inference that their development is not only very extensive, but practically available through its entire extent. (See Table No. IV., paragraph 226, for analysis.)

75. *The Round Top Cement Works* are located about three miles above Hancock, Md., on the Chesapeake and Ohio Canal. The mill, which stands on the tow-path between the Potomac River and the canal, comprises two run of four feet French burrs, driven by a forty-horse water-power, derived from the discharge of the water of the canal into the river. The kilns resemble those at Shepherdstown (Figure 11), and Cumberland coal is used for burning.

The Round Top Cement Works.

76. The cement layers at this place crop out on the left bank of the Potomac, and have been cut off for the excavating of the canal. They are exceedingly crooked and tortuous, bending up and down, and doubling upon each other in a very complex manner. Their aggregate thickness is about 48 to 50 feet, comprising eleven distinct layers, each possessing marked and peculiar properties.—Commencing at the top:

Aggregate thickness of deposit.

Number One, 8 feet thick, is highly argillaceous, and is very hard and difficult to grind after calcination. It sets slowly, and will not bear immersion, unless first allowed to set in the air.

Number Two, 4 feet thick, is mostly argillaceous slate, and

is rejected. Portions of good cement stone are sometimes found mixed with it.

Number Three, one foot thick, is a good cement when properly treated, and hardens readily under water.

Number Four, 4 feet thick, is too calcareous to be used for cement alone. When suitably *underburnt* it possesses a moderate degree of hydraulic activity but is rendered almost worthless, if exposed to heat of sufficient intensity and duration to burn the other layers of the quarry properly. It is therefore rejected.

Characteristic features of the several layers.

Number Five, 5 feet thick, furnishes a remarkably quick cement, when the calcination is arrested at the point of complete expulsion of the carbonic acid gas. Beyond this point it will bear immersion in the state of paste, but does not harden so quickly as when in the condition of sub-carbonate.

Number Six, one foot thick, is nearly pure carbonate of lime and is rejected.

Number Seven, 6 feet thick, burns dark colored, like the Rosendale cements, but is not a quick cement by itself. It is used in the combination.

Number Eight, 4 feet thick, resembles Seven, though superior to it.

Number Nine, 5 feet, contains an excess of carbonate of lime, and is, in fact, an energetic hydraulic lime. It is used in the combination.

Number Ten, one and a half feet thick, is a slate. Rejected.

Number Eleven, 11 feet thick, gives a quick and energetic cement, which hardens readily under water. It is depended upon, in a measure, to confer hydraulic activity on the combination, whenever from bad burning, carelessness in assorting the stone, or any other cause, there is deficiency in this particular.

With the partial exception last mentioned, the layers that are used are combined together in the proportion of their developed thickness in the quarry.

The Round Top quarries contain a very large amount of cement stone, so situated, on the slope of the river and canal, as to secure to the manufacturer every advantage which position can afford. (See Table IV., paragraph 226, for analysis.)

77. *The Cumberland Cement Works* are located at Cumberland City, Md., and comprise two run of French burrs, 4½ and 5 feet in diameter, respectively, driven by a 35-horse-power engine. This power is considered sufficient to drive three run of stone. Three kilns, burning Cumberland coal, and resembling those used in Ulster Co., N. Y., are in operation. Cumberland Cement Works.

78. The cement stone is derived from two quarries, situated in close proximity to each other, on Will's Creek, near its junction with the Potomac. The principal bed is from 35 to 40 feet thick, of which the lower half furnishes a slow cement, that will not indurate under water unless first allowed to set in the air, and, even then, rather slowly. The upper half yields a cement that will bear immersion in the state of paste. Each of these two layers furnishes one-third of the combination, the remainder being derived from a nine-feet ledge a few yards distant, which is quarried by tunnelling. It is quick-setting. Below this there are other layers of good cement, which are not at present used on account of the extra expense of quarrying, and one or two thin beds of argillo-magnesian limestone, possessing the properties of intermediate limes. For analysis of Cumberland cement, see Table IV., paragraph 226.

79. *The James River Cement Works* are located at Balcony Falls, Rockbridge county, Va., on the James River, and the James River and Kanawha Canal. The mill stands on the tow-path, and contains two crackers and four run of French burr-stones of medium size, driven by water-power derived from a dam across James River, erected by the Canal Company. The power is deemed sufficient to turn six run of stone. Six kilns, as represented in Figure 11, are located at the mills The quarries, of James River Cement Works.

which there are two opened in the same stratum, are on the margin of the river, about one mile above the mill, from which point the stone is transported to the kilns in boats, on the slack water of the dam. This deposit is generally known in Virginia as the "Blue Ridge quarry." The writer visited these rocks in the summer of 1858, under orders from the Engineer Bureau of the War Department. The following is an extract from his report, rendered on the 31st of July of that year:

"The cement vein or stratum is twelve to thirteen feet thick, and dips to the northwest fifty-five degrees (55°). It crops out on the summit of an undulating table-land, or, perhaps, more properly, a ridge situated at the base of the mountain. The direction of the outcrop is nearly northeast and southwest. The upper ridge of the stratum changes its character very materially before it reaches the surface, gradually disappearing in a soft, porous yellow stone, which in turn runs into a hard clay, of various shades of yellow and light orange, and in various stages of decomposition. This becomes perceptibly softer as it approaches the surface; the upper portion, to the depth of several feet, yielding readily to the pick and shovel. The entire bed is subdivided into layers, varying in thickness from one and a half to four feet." . . . . . "The color of the raw stone is dark blue, its texture compact, grain moderately fine, and fracture slightly conchoidal." For the analysis, see Table IV., paragraph 226. The James River Works, driven to their full capacity, will turn off 350 to 400 barrels of cement daily. It is sent to the eastern markets viâ the James River and Kanawha Canal, and James River.

Description of cement deposit.

80. At *Utica*, Lasalle county, Illinois, cement is manufactured from a bed of stone seven feet thick, which crops out on the margin of Illinois River, just above the level of high water. It is burnt with bituminous coals in intermittent kilns of about 200 barrels capacity. It is stated by one of the manufacturers that perpetual kilns

Cement at Utica, Lasalle county, Illinois.

would not discharge the burnt stone readily, on account of the thin slaty fragments into which it splits in quarrying. Two parties are engaged in its manufacture. One of them has eight kilns and three run of stone (two of four feet and one of four and a half feet diameter); the other has three kilns and one run of four feet stone. Steam-power is used for grinding. The full capacity of both works is stated at 700 to 800 barrels per day. (For analysis, see Table IV., paragraph 226.)

81. *The Sandusky Cement Works* are in Van Rensselaer township, Ottawa county, Ohio, on the point of the peninsula opposite Put-in-Bay Island, and near Hat Island. The thickness of the cement deposit is not accurately known. It is nearly horizontal, and is quarried in three or four places to a depth varying from five to eight feet, down to the level of the water of Lake Erie. The stone is burnt in perpetual kilns with coal, either bituminous or anthracite, in a manner similar in every respect to that pursued in Ulster county, New York. The mill is driven by steam-power, and comprises four run of French burrs with the requisite number of crackers, and is capable of grinding 300 barrels per day. (See Table IV., paragraph 226, for analysis.)

Sandusky, Ohio, Cement Works.

82. Near *Louisville*, *Kentucky*, at the foot of the falls of the Ohio River, there is a deposit of cement stone, which for many years has been extensively used throughout the West, and particularly along the Mississippi River. The deposit is six feet thick; the stone is burnt in the ordinary draw-kilns (Figure 12), anthracite coal being used for fuel. The mill contains one pair of four and a half feet French burrs, driven by water-power.

Cement at Louisville, Ky.

As early as the year 1848, Col. Long, of the Corps of Topographical Engineers, who had witnessed the successful application of the Louisville cement to building purposes in the West, entertained a very high opinion of its quality, and pronounced it, when used "in the formation of subterraneous and submarine foun-

Col. Long's opinion of the Louisville cement

dations, and other structures in similar situations, a cement unsurpassed by any materials of the kind hitherto employed for such purposes in this or any other country." *

* The cost of manufacturing cement varies, of course, among the different works, according to local circumstances, such as the kind of motive power used for milling, the proximity of the kilns to the quarries and to the mill, the dip of the strata, and the proportion of quarried stone not suitable for use, the character of the burnt stone with respect to hardness, &c., &c.

The Rosendale cements, on account of the superior facilities, and the brisk competition among the manufacturers, are produced at less expense than any in the country. Great pains have been taken to obtain data for a correct estimate of this expense.

The following table is based upon a work whose estimated capacity is 300 barrels per day, on the supposition that the kilns and mills are in such proximity that the transportation of the raw stone to the kilns, and of the manufactured product to the canal, can all be accomplished with five single teams. In some works it is considerably below this estimate.

CURRENT ANNUAL EXPENSES OF A CEMENT MANUFACTORY OF 300 BARRELS DAILY CAPACITY, WORKING 200 DAYS IN THE YEAR:

Salary of Superintendent		$ 800 00
" " 1 Engineer		500.00
" " 1 Fireman	$1.00 for 200 days	200.00
" " 1 Smith	1.25 " " "	250.00
" " 13 Quarrymen	1.00 " " "	2,600.00
" " 5 Single Teams	1.75 " " "	1,750.00
" " 1 Head Burner	2.00 " " "	400.00
" " 3 Assistant Burners	1.00 " " "	600.00
" " 4 Drawers	1.00 " " "	800.00
" " 1 Miller	1.75 " " "	350.00
" " 1 Assistant Miller	1.25 " " "	250.00
" " 5 Packers	1.00 " " "	1,000.00
Powder for blasting 14,049 Tons of Stone		1,200.00
Coal for burning " " "		2,700.00
Coal for engine, $4.00 per day, 200 days		800.00
Paper and nails for packing, 1½c. per barrel		900.00
Total Expenditure		$15,100.00
Add 15 per cent. for incidental and contingent expenses, accidents, delays, wear and tear		2,235.00
Annual consumption of quarry, based on total consumption in 12 years		1,000.00
Interest on capital invested, $30,000 at 7 per cent		2,100.00
Insurance on building and machinery, $18,000 at 2 per cent		360.00
60,000 new barrels delivered at the works, at 28c		16,800.00
Total cost of 60,000 bbls. of cement, ready for delivery at the work.		$37,595.00
Cost per barrel at the work, ready for delivery		62 5/10

83. At *Kensington, Conn.*, a cement has been manufactured for many years, which has never found a distant market in large quantities, owing to the expensive land transportation to which it would be subjected, and which precludes its ever coming in competition with the Rosendale cements, for general use. A marked superiority for stucco-work in exposed positions is claimed for it by the proprietors, on the authority of the late A. J. Downing, Esq., who gave it a preference over all others for that particular purpose. The mill is driven by water-power, and contains two run of four feet Esopus Stone (Shawangunk grit). The deposit of cement-stone is about three miles from the mill. Its thickness varies from one to eight feet.

Cement at Kensington, Conn.

84. Cement manufactories also exist at Akron, Erie county, New York, at Lockport and Fayetteville, New York, and at other points on the line of the Erie Canal. The cements from Manlius and Chittenango, New York, rank in point of hydraulic activity between the genuine cements and the eminently hydraulic limes, some portions of the quarries partaking largely of the character of intermediate limes. These two last-named cements require to be used with great care.

Cement manufactories at Akron, Manlius, and Chittenango, N.Y.

85. Besides the foregoing cements, two well-known imported varieties have been introduced to a limited extent into these trials, viz.: the artificial Portland cement of England, and Parker's Roman cement. As these cements are both extensively used in Europe, and have been submitted to a great many trials, their character and value are well known among those who have given the subject attention. They therefore furnish us the means of comparing mortars made from our products with those in common use throughout Europe. In Europe, all natural cements are generally denominated Roman cements, to distinguish them from Portland cements, which are artificial combinations of limestone (usually chalk) and clay.

Roman and Portland cements.

ROMAN CEMENT.

86. This cement is manufactured in both England and France, by a process essentially similar to that pursued in making cement in this country. It is derived from argillo-calcareous, kidney-shaped stones called "Septaria," belonging to the Kimmeridge and London clay, generally gathered on the sea-shore after storms and high tides, though sometimes obtained by digging. The manufactured article usually takes its name from the locality which furnishes the stone, as "Boulogne" Roman cement, "Harwich" or "Sheppy" Roman cement. The several brands possess almost identically the same composition. (See Table IV., paragraph 226.)

Source of Roman cement.

NATURAL PORTLAND CEMENT.

87. A cement is manufactured by MM. Demarle & Co., of Boulogne-sur-mer, from one of the layers of the Kimmeridge clay, situated about 160 feet below the strata in which the "Boulogne pebbles" or "Septaria" are found. The deposit is argillo-calcareous, and is burned and ground up for cement in its natural state without the addition of lime, furnishing the so-called Natural "Portland" cement. It was exhibited in Paris at the Palais de l'Industrie, in 1855, and a report thereon by M. Delesse, Engineer of Mines, sent to me by the manufacturers, has supplied the following particulars:

Natural "Portland" cement of Boulogne-sur-mer.

No locality, except Boulogne, is known to furnish a soft deposit that can be excavated with pick and shovel, possessing in suitable proportions all the ingredients of good cement. The calcareous clay which is used in making "Portland" cement is found in the Inferior Cretaceous Formation. Its paste is nearly homogeneous, and contains from nineteen to twenty-five per cent. of clay. The proportions of silica and alumina

Comes from the Inferior Cretaceous Formation.

Percentage of clay contained.

contained in the latter may vary, without any inconveniences resulting therefrom; but it is important to avoid sand, as far as possible. Accordingly, those portions containing more than one-twentieth of sand are rejected.

88. It is known, that in order to obtain *artificial* "Portland" cement, it is by no means necessary to use exclusively the argillaceous mud deposited by certain rivers: the limestone may be mixed with either marls or clays, the only necessary condition being to secure a perfectly homogeneous mixture of carbonate of lime and clay, in the above-mentioned proportions. It is, moreover, indispensable that the mixture should be quite intimate, otherwise, even with the required proportions, it may fail to yield good "Portland" cement. For this reason, M. Dupont, the patentee, has adopted for grinding the original materials for the natural "Portland" cement, horizontal mill-stones, similar to those used for grinding corn. Instead of using a great quantity of water, in order to separate the materials by levigation, as is practised in the English process, he adds only enough to form a plastic paste. Immediately after this paste has passed under the mill, it is shaped into small bricks, which are placed in the kiln as soon as they are properly dried. As above intimated, a most essential condition of the paste is that its composition should be quite homogeneous, otherwise the portions richest in silica would fuse and form a silicate, which could not enter into combination with water.

Mills for grinding the calcareous clay.

89. During the calcination, it is of the utmost importance to have the temperature sufficiently elevated. The ordinary temperature of lime-kilns would be far too low, for that would merely drive off the water and carbonic acid. The materials must receive a white heat, whereby they can become slightly agglutinated. The state of incipient vitrification appears to be the proper limit of calcination.

Must be burnt at a high heat, producing incipient vitrification.

90. Moreover, a high heat, however intense, is not ob-

jectionable, as only those portions that would have injured the quality of the cement will become completely fused. This fusion will then afford the means of separating and excluding those parts which do not possess the proper composition, and are unfit for use.

Assorting the burnt clay.

91. After the calcination, a selection is necessary; the pulverulent and scorified portions of the mass are picked out and thrown away.

92. *Properties.*—When taken out of the kiln, it is in the shape of fragments warped and cracked by contraction, and of a gray and slightly greenish color. Its powder has a somewhat paler shade. The weight of one cubic metre of loose powder is 1,270 kilograms (2,136 pounds to the cubic yard), which will sometimes reach 1,385 kilograms (2,329 pounds per cubic yard). The Boulogne "Portland" cement, therefore, has a greater specific gravity than the English "Portland," as that from Newcastle weighs only 916 kilograms to the cubic metre, and that from London 1,057 kilograms (1,541 and 1,778 pounds per cubic yard, respectively). During the mixing with water in forming paste, the Boulogne "Portland" undergoes a diminution in volume of .3, the same as the Boulogne "Roman" made from "Septaria." The volume of water which combines with it in mixing is .366, according to M. Dupont. In weight, 1.00 of "Portland" cement, therefore, absorbs .29 of water, which shows that, for an equal weight, the Boulogne "Portland" cement requires far less water than the Boulogne "Roman" cement. This difference is doubtless due to the high temperature at which the "Portland" cement is burnt. The same cause also explains its slow setting, which does not take place until after twelve, or even eighteen hours.

Weight of the Boulogne "Portland" cement compared with that of artificial "Portland."

The Boulogne "Portland" absorbs less water than the Boulogne "Roman." It is slower setting.

93. This property of setting slowly may be an obstacle to the use of the Boulogne "Portland" cement for hydraulic work

which have to contend against immediate causes of destruction, as, for instance, sea constructions which have to be executed under water between tides. It is, however, possible, in the last-mentioned case, to obviate this inconvenience by temporarily covering the "Portland" with a quick-setting cement.

Slow-setting cements objectionable, under some circumstances.

"Moreover, a quick-setting cement is always difficult to be used; it often requires special workmen, and, at all events, a very active supervision. A slow-setting cement, like the natural "Portland" of Boulogne, possesses the great advantage of being manageable by ordinary masons, and can be mixed up with additional water after twelve, or even twenty-four hours.

Advantageous under others.

94. M. Delesse, in the report which furnished the foregoing details, remarks: "We have made, in the laboratory, some gangs with Boulogne 'Portland' cement. The sample upon which we operated, and the composition of which we give below, was in fragments, and the gangs were made directly after the cement had been ground. After a few days, they displayed cracks showing contraction. As the cement exhibited at the Palais de l'Industrie showed no cracks, these were probably due to the fact that the cement experimented upon was fresh from the kiln, whereas ground cement, after being stored for some time, becomes more or less hydrated, and is less liable to contraction. We observed, moreover, that the water in which the gangs were immersed was impregnated with a considerable quantity of lime. In the natural 'Portland' the lime is therefore in excess, and the whole of it does not enter into combination to form hydrosilicate.

95. "The composition of the natural Boulogne 'Portland' cement is as follows:

"Lime	65.13
Magnesia	.58
Silica	20.42
Alumina and small quantity of oxide of iron	13.87
Sulphate of lime	a trace."

Analysis of the natural Boulogne "Portland" cement.

In analyzing the same cement, M. Vicat found only 61.75 of lime. This composition comes very near that of the English artificial "Portland," which is given in paragraph 131. They are both classed among the intermediate limes of Vicat. The calcination of these cements, at a temperature producing vitrification, develops a peculiar state of combination of the ingredients, which confers upon them their remarkable properties.

CHAPTER IV.

96. The calcination of statuary marble, or any other pure variety of limestone, produces quicklime, by expelling from the carbonate of lime ($CaO.CO_2$), of which they are essentially composed, the carbonic acid gas, (CO_2), water of crystallization, and organic coloring matter. Lime is therefore a protoxide of calcium, or, in other words, a metallic oxide, the base, calcium, having been classed, since Sir H. Davy succeeded in effecting the decomposition of *lime*, among the metals. Pure lime (CaO) has a specific gravity of 2.3, is amorphous, somewhat spongy, highly caustic, quite infusible, possesses great avidity for water, and, if brought in contact with it, will rapidly absorb .22 to .23 of its weight, passing into the condition of hydrate of lime, a chemical compound, of which the formula is CaO.HO. The reactions resulting from this combination are attended with certain marked phenomena, such as a great elevation of temperature, the bursting of the lime into pieces with a hissing and crackling noise, the evolution of a hot and slightly caustic vapor, and finally, after a few minutes, its reduction into an impalpable powder, of which the volume is about three and a half times that of the original lime. In this condition the *lime* is said to be *slaked*.

Lime a metallic oxide, and how produced.

Its characteristics.

Phenomena developed in "slaking."

97. Water dissolves, according to Sir H. Davy, about one four-hundredth of its weight of lime, or, according to Thomson,

one seven hundred and fifty-eighth, while Dalton states it to be, at 60° F., one seven hundred and seventy-eighth, and, at 212°, one twelve hundred and seventieth. The solutions, commonly called lime-water, are valuable re-agents and antacids. Lime being more soluble in cold than in hot water, its solution becomes turbid when boiled. A similar result is produced by breathing into a solution through a tube, owing to the carbonate of lime formed by respiration, which, however, is dissolved by an excess of carbonic acid gas. A paste of the slaked lime is therefore a mixture of the hydrate of lime and lime-water. It will remain in a soft condition for an indefinite period, if kept in a damp place, excluded from direct contact with the atmosphere.

Solubility of lime in water.

98. Lime, on account of its great affinity for moisture, and, when moist, for carbonic acid, absorbs them gradually from the atmosphere, returning to the state of carbonate of lime, with an excess of hydrated base ($CaO.CO_2 + CaO.HO$). To protect it against the effects of these deteriorating agents, it is necessary to preserve it in close vessels.

It absorbs moisture and carbonic acid from the air.

99. Lime may be distinguished by its dilute solution giving a white precipitate of oxalate of lime, when a solution of oxalic acid is added to it, which is not redissolved by an excess of oxalic acid; and by not yielding a precipitate with sulphuric acid and sulphate of soda.

Test for lime.

100. The purest minerals of the calcareous class are the rhombohedral prisms of calcareous spar, the transparent double refracting Iceland spar, and white or statuary marble. They are entirely dissolved in dilute hydrochloric acid, with a brisk effervescence, due to the escape of carbonic acid gas, and contain, according to an analysis of a specimen of white marble by General Treussart, about .33 parts of carbonic acid, .64 of lime, .03 of water. In pure carbonate of lime the lime amounts to .56 of the whole.

The purest calcareous minerals.

101. The limestones which furnish the limes of commerce are

seldom if ever pure, but usually contain, besides the carbonate of lime and the water of crystallization, variable proportions, seldom exceeding .10 in the aggregate, of some if not all of the following impurities, viz.: silica, alumina, magnesia, oxide of iron and oxide of manganese, and sometimes traces of the alkalies, the presence of which modifies to a greater or less degree the phenomena developed during the process of slaking, as noticed in paragraph 96, and renders necessary certain precautions in their manipulation and treatment, when employed, for the purposes of construction, as mortars.

Limestones are seldom pure.

Phenomena developed in slaking.

102. The striking and characteristic property of hardening under water, or when excluded from the air, conferred upon a paste of lime by these foreign substances, when their aggregate amount exceeds .10 of the whole, furnishes the basis for a general arrangement of all natural or artificial products suitable for mortars, into five distinct classes, as follows:

1st. The common or fat limes.
2d. The poor or meagre limes.
3d. The hydraulic limes.
4th. The hydraulic cements.
5th. The natural pozzuolanas, including pozzuolana, properly so called, trass or terras, the arènes, ochreous earths, schists, grauwacke and basaltic sands, and a variety of similar substances.

Their classification as sources of mortar.

103. The *common*, *fat*, or *rich* limes usually contain less than 10 per cent. of the impurities mentioned in paragraph 101. In the process of slaking to a paste, their volume is augmented to from two to three and a half times that of the original mass, accompanied by a hissing noise, an elevation of temperature, and the rapid and progressive reduction of the lime to powder, and finally, if sufficient water be added, to a homogeneous and consistent paste. With the exception of a portion of the foreign substances mentioned, it is soluble to the last degree in water frequently changed. If

Common lime.

Its increase of volume in slaking.

made into a stiff paste, it will not harden under water, or even in damp localities excluded from contact with the air, or under the exhausted receiver of an air-pump. In the air, it hardens by the gradual formation of carbonate of lime, due to the absorption of carbonic acid gas, aided by the deposition of crystals of hydrate of lime from the lime-water of mixture, during the process of desiccation.

The paste will not harden under water.

Theory of its induration in the air.

104. The pastes of fat lime shrink in hardening to such a degree that they cannot be employed as mortar without a large dose of sand. When used alone, they are unsuitable for masonry under water, or for foundations in damp soils; but in other situations, have an extensive application, possessing, as they do, great advantages over the other limes on the score of economy, on account of the large augmentation of their volume in slaking, their extensive distribution over the surface of the globe, and the simplicity of their process of manufacture. Paste of fat lime may be added to a cement mortar, in quantities equal to that of the cement, without material diminution of strength.

Use of sand.

Lime mortars unsuitable for subaqueous works; much used under other circumstances.

105. The *poor* or *meagre* limes generally contain silica (in the shape of sand), alumina, magnesia, oxide of iron, sometimes oxide of manganese, and in most cases traces of the alkalies, in relative proportions which vary very considerably in different localities. Their aggregate amount is seldom less than .10 or greater than .25, although, in some varieties, it reaches as high as .35, and even, though rarely, .39 of the whole. In slaking they proceed sluggishly, as compared with the rich limes, and seldom produce a homogeneous and impalpable powder. They exhibit a more moderate elevation of temperature, evolve less hot vapor, and are accompa-

Poor or meagre limes.

Amount of impurities which they contain.

Phenomena developed in slaking.

nied by a much smaller increase of volume than the rich limes. Like the latter, they dissolve in water frequently renewed, though more sparingly, owing to the presence of a larger amount of impurities, and like them will not harden, if placed in the state of paste, under water or in wet soil, or if excluded from contact with the atmosphere, or carbonic acid gas. They should be employed for mortar, only when it is impossible to procure common or hydraulic lime, or cement, in which case it is recommended, if practicable, to reduce them to powder by grinding. As a fertilizer, they have an extensive application.

Not to be used for mortars, except under precautions.

106. A very large proportion, frequently .90 of the silica, contained in meagre limes, is in the state of inert grains of sand, which accounts for the frequent absence of those peculiar properties of hardening or "setting" under water, which would place them in one of the classes of hydraulic limes, were the silica present, or a suitable proportion of it, in a more appropriate form.

Inert silica in meagre limes.

107. The *hydraulic limes*, including the three subdivisions of "*limes slightly hydraulic*," "*hydraulic limes*," and "*limes eminently hydraulic*," seldom contain an aggregate of silica, alumina, magnesia, oxide of iron, &c., exceeding .35 of the whole. The proportion in the *first* class ranges generally between .10 and .20 of the whole; in the *second* class, between .17 and .24; while the eminently hydraulic limes contain rarely less than .20, or more than .35 They all slake under proper treatment, though more slowly than the meagre limes, with but a slight elevation of temperature, the disengagement of little or no vapor, and but a small augmentation of volume, rarely exceeding .30 of the original,—their appearance presenting in this respect a striking contrast with the phenomena exhibited during the slaking of rich limes.

Hydraulic limes. Three classes.

Amount of impurities which they contain.

Phenomena developed in slaking.

If mixed into a stiff paste, after being slaked, they possess

Their paste will harden under water.

the valuable property of hardening under water, in periods varying from fifteen to twenty days after immersion, if "slightly hydraulic;" six to eight days, if "hydraulic;" and one to four days, if "eminently hydraulic." As a general fact, these limes undergo, in slaking, an increase of volume, inversely proportional to their hydraulic energy and quickness.

Why classed between common lime and hydraulic cement.

108. The hydraulic limes, in their chemical composition, as well as in those qualities which confer value in their application to the purposes of construction, and, in their geological position, occupy an intermediate place between the *common* or *fat* limes and the hydraulic cements. They are consequently found in the United States in numerous and extensive deposits; but as they possess no valuable property not present in a pre-eminent degree in those limestones which furnish hydraulic cement, it has not been found necessary, and certainly it would not be remunerative, to engage in any extensive manufacture of them for the trade.

Found extensively in the United States, but not manufactured for use.

109. The *hydraulic cements* contain a larger amount of silica, alumina, magnesia, &c., than any of the preceding varieties of lime, though the amount rarely, if ever, exceeds .61 of the whole. They do not slake at all after calcination, differing materially in this particular from the limes proper. If pulverized, they can be formed into a paste with water, without any sensible increase of volume, and with little, if any disengagement of heat, except in certain instances among those varieties which contain the maximum amount of lime, or border on the "intermediate limes." They are greatly superior to the best "eminently hydraulic limes," for all the purposes of hydraulic construction; some of them being so energetic as to "set" under water at 65° F.,

Hydraulic cement.

Will not slake.

Water does not cause increase of volume.

A paste will harden quickly under water.

in three or four minutes, although others require as many hours.

Do not shrink in hardening, and may be used without sand.

They do not shrink in hardening like the paste of fat lime, and therefore make an excellent mortar without any addition of sand; although, for the sake of economy, sand, and frequently both sand and lime, are combined with them. In the United States, they are almost exclusively depended upon for hydraulic mortar.

110. Lying between the two preceding classes in the amount of foreign substances which they contain, and possessing such characteristic features as to entitle it, perhaps, to a separate notice, if not a separate classification, there is a class of compound limestone prominently developed in the argillo-magnesian deposits of this country, possessing in a very marked degree all the objectionable properties of the argillaceous intermediate limes (*chaux limites*), noticed by M. Vicat. When *completely* calcined, they set rapidly, both in the air and in water; but in the latter case are soon thrown down by the slaking of the meagre caustic lime, which they contain in excess. This result is brought about either by the appearance, soon after submersion, of a fine network of cracks, all over the surface of the mortar, which gradually penetrate into the interior until the whole is reduced to a granulated or lumpy paste, possessing no cohesion, or, by the progressive softening of the whole mass, to a fine and homogeneous pulp, frequently accompanied in either case with a considerable enlargement of volume.

Intermediate limes of the United States.

Their characteristic features.

Action of their paste under water.

If, after the action of the water has commenced, as indicated either by the appearance of cracks, or by a general softening upon the surface, the paste be again worked up with the trowel, dried off with bibulous paper, formed into a stiff cake and immersed, the same phenomena, though in a more moderate form, will frequently exhibit themselves again, and with some varieties,

Destruction of hydraulic energy thereby.

will not entirely disappear, until four or five repetitions of this process. This is particularly the case with some of the layers in Ulster county, N. Y. In all cases, however, whether one or several remixings suffice, the hydraulic energy is so far impaired that the substance cannot assume a higher rank than hydraulic lime, requiring from three to ten days to harden sufficiently to support the $\frac{1}{24}$ inch wire loaded to one pound. When considerably underburnt, these limestones yield a good cement. They ought not, under any circumstance, to be introduced, even in a small proportion, into any combination which is intended to be kept up to the standard of good cement, without being subjected to a calcination by themselves; and even then it will be found extremely difficult, if not practically impossible, to so regulate the heat that all the stone shall be suitably *underburnt.*

Not to be used for mortar, except under certain precautions.

111. The *natural pozzuolanas* comprise pozzuolana properly so-called, trass or terras, the arènes, some of the ochreous earths, and the sand of certain grauwackès, psammites, granites, schists, and basalts. Their principal ingredients are silica and alumina, with a large preponderance of the former. Most varieties contain small quantities of soda, potash, oxides of iron and manganese, and not unfrequently magnesia. None of them contain more than .10 of lime. When finely pulverized without previous calcination, and combined with the paste of fat lime in suitable proportions, to supply their deficiency in that ingredient, they possess hydraulic energy to a degree that will compare favorably, in some of the varieties, with that of the "eminently hydraulic limes." Those derived from the disintegration of grauwackè, psammite, granite, and the other rocks mentioned, are the least energetic of the class, and are somewhat improved by a slight calcination.

Natural pozzuolanas.

Principal ingredients thereof.

Are hydraulic when pulverized and mixed with fat lime.

Some varieties improved by calcination.

112. *Pozzuolana*, which confers the name upon this class of substances, is of volcanic origin, and has therefore been subjected to the action of heat, whereby its constituent elements have experienced a chemical change in their primitive mode of combination. It was originally discovered at the foot of Mount Vesuvius, near the village of Pozzuoles, whence its name, although it is common to all localities that have been exposed to igneous agency, being found sometimes upon the surface of the earth, though most generally in beds, which frequently extend to considerable depths. It is extensively disseminated throughout Europe, and large quantities for building purposes, have been derived from the vicinity of Rome and Cività Vecchia, in Italy, and from the Puy-de-Dôme, Upper Vienne, Upper Loire, Cantal and Vivarais, in France. It is also found in Sicily, in the Isle of France, and in Guadaloupe and Martinique. It sometimes exists in a coherent form, but more frequently is either pulverulent or in coarse grains, sharp, angular, and rude to the touch. Its prevailing color is brown, with many exceptional shades of red, violet, gray, and yellow, and oftentimes approaching white and black. It is highly magnetic, parts with about .09 of water by calcination, is entirely solvent in sulphuric acid, and in concentrated hydrochloric acid at the boiling point. As might be inferred, from the character of the agencies which produce pozzuolana, its hydraulic properties differ very much in different localities.

Pozzuolana; its origin.

Found extensively in Europe.

Localities.

Color.

Properties.

Its value for the purposes of construction in combination with rich lime, has been known for many centuries, and Vitruvius and Pliny both speak of its admirable properties, as exhibited in the marine constructions of the Romans, extant in their day. In using pozzuolana, it is customary after pulverizing it, to add sand as well as lime; the relative proportion of the three ingredients

Known to the ancients.

depending on the kind of sand employed, and the character of the lime and pozzuolana. For the Italian pozzuolana, there is perhaps no better combination than that recommended by Vitruvius himself, which has been followed, with slight variations, very generally throughout Italy, and at Toulon, and other ancient ports on the French coast. It is as follows, viz.:

12 parts of pozzuolana well pulverized,
6 " " quartzose sand well washed,
9 " " rich lime recently slaked; to which is added
6 " " fragments of broken stone, porous and angular, when it is intended for a pisé or a filling in.

Not known to be native to the United States.

The pozzuolanas of this country, if any exist, have never been used in constructions, and have never been examined with that view.

113. *Trass or terras.*—In the valley of the Rhine between Mayence and Cologne, and in various localities in Holland, a substance of volcanic origin is found, called Trass or Terras, which has been extensively employed throughout that region, particularly by the Dutch engineers, for the production of hydraulic mortar. It is derived from immense pits or quarries, occupying the sites of extinct volcanoes, and enjoys in nearly every particular the distinguishing properties of Italian pozzuolana, closely resembling it in its composition, and in the details of its manipulation, requiring to be pulverized and combined with rich lime, in order to render it fit for use, and to develop any of its hydraulic properties.

Trass.

Its sources.

Resembles pozzuolana and is used in the same manner.

114. The trass used in Holland is obtained principally from Bonn, Andernach, and from the village of Dordreck, exclusively devoted to its production, and at the confluence of the Rhine and the Meuse.

Localities of Dutch trass.

115. Trass is of a grayish color, has an earthy appearance, and is found in beds that are sometimes coherent, though usually composed of a hete-

Color.

rogeneous mass of pulverulent lumps, from the size of a small pea to that of an egg. Sulphuric, and even concentrated hydrochloric acid, attacks it with readiness, leaving a residue of insoluble silica. Smeaton regarded it as inferior to the Italian pozzuolana in some essential particulars, and mentions, as one of its objectionable features, that of throwing out unsightly efflorescences upon the faces of walls in which it is used, which attain such a degree of hardness, as to render their removal with instruments necessary, specially in positions where smoothness and regularity of surface are essential, as in water conduits, navigable sluices, &c.

Properties.

More recent experiments have led to the suspicion that Smeaton either made use of a lime ill adapted to the purpose, or what is perhaps more probable, that he unduly augmented its proportion, which should rarely exceed the ratio of one to one.

116. *Arènes* is the name given to a species of ochreous sand, claimed by some to be of fossil origin, and found abundantly in France, in the Department of Dordogne, and in several localities on the tributaries of the Loire and the Somme. On account of the large proportion of clay which many of them contain, which often reaches as high as .70, they can be formed into a paste with water, without any addition of lime, and are often used in that state for the walls of buildings constructed *en pisé*, as well as for mortar.

Arènes.

Are hydraulic without lime.

Mingled with rich lime, they give apparently excellent mortars, which attain great hardness under water; and, in hydraulic quickness, compare favorably with the most energetic hydraulic limes.

117. It is doubtful, from some careful experiments that have been made, whether their properties, as regards the ultimate strength and hardness of the mortars made from them, are improved by calcination, or otherwise. Their hydraulic quickness, however, is greatly increased thereby. Their colors are various, such

Their hydraulic activity increased by burning.

as red, brown, yellow, and sometimes white. They contain from .10 to .70 of clay, the balance being a mixture of coarse and fine calcareo-silicious sand; and have hitherto been principally found upon the summits of small hills, or forming the superior strata of plateaux bordering water-courses, but rarely in the valleys. These beds exhibit the characteristic physical features of alluvial deposits, and are probably accretions of diluvial or tertiary earths, transported from a distance. This conclusion excludes the idea that they have been subjected to the action of volcanic heat, and leaves us to account by some other hypothesis for their hydraulic properties, and their close resemblance, in other respects, to the Italian pozzuolana. The most reasonable supposition is that they owe their hydraulic energy, when mixed with the paste of fat lime, to the presence of silica, not in the state of quartz, but in a form favorable to its free combination with the lime, in the production of an insoluble silicate. To account for the hydraulic energy in *crude* arènes requires a more lengthy discussion of certain chemical reactions, than can with propriety be introduced here. It will therefore be deferred to the chapter containing the "theory of the subaqueous induration."

Composition.

Probable theory of their hydraulicity.

118. When the arènes were first discovered, great attention was paid to their examination, and with such favorable results at the outset, that they immediately took rank among the most valuable sources of hydraulic mortar. Subsequent experiments, however, have not fully realized the high expectations originally entertained with regard to them, or verified their claims to any superiority in initial energy over the pozzuolana and trass; while the effects of time upon the mortars composed of them, have established the fact that, with few exceptions, they should be classed among the most feeble pozzuolanas, that they contain ingredients which exercise a hurtful influence upon mortars in the air, and that immersed in water, they attain but a medium degree of ultimate hardness.

119. Properties similar to those possessed by the arènes have been discovered in grauwackè, psammite, granite, schist, basalt, and other rocks, when in a state of disintegration. They must, however, be considered as very feeble pozzuolanas, in the crude state, and acquire but a slight increase of hydraulic energy by any degree of calcination. Even their feeble powers, however, confer upon them this advantage, that, for mortars not absolutely immersed in water, when green, and when there is ample time for their properties to develop themselves before submersion, they can be employed in larger proportions than any species of sand, wholly inert, would admit of.

Other natural pozzuolanas.

120. It may be said that a mortar has *set*, when it has attained such a degree of induration, that its form cannot be altered without causing a fracture, that is, when it has entirely lost its plasticity. As the precise moment when this takes place is somewhat difficult to ascertain in practice, it is important that some more rigorous standard of comparison should be established. The common method is to make use of an iron or steel wire point loaded to a given weight; and the mortar is assumed to have set, when it has become sufficiently stiff and firm to support the point without depression.

The "setting" of a mortar defined.

Determination of the time of setting.

121. Some cements are remarkably quick in exhibiting their hydraulic property, and will lose their plastic state immersed in water at 65° F. in one or two minutes, but afterwards proceed very sluggishly in their induration. These, therefore, setting aside the question of their value in other respects, are admirably adapted to constructions under water, or in positions subjected to immediate submersion. There are others, again, which, though comparatively slow in developing the first indications of hydraulic energy, yet in a few hours, greatly surpass the former in withstanding the wire test, as well as in their ultimate strength and hardness, and are therefore to be

preferred in all positions where a very quick induration is not specially important. The former are remarkable for what we propose to term *hydraulic quickness* or *activity;* the latter, for *hydraulic energy* or *power.* In order that we may be able to detect and recognize these somewhat obscure properties, it is necessary to have at least two testing wires, which differ either in their size, or weight, or in both. General Totten, for his experiments, carried on at Fort Adams, R. I., during several years prior to 1830, used a $\frac{1}{12}$ inch wire, loaded to weigh $\frac{1}{4}$ of a pound, and a $\frac{1}{24}$ inch wire, loaded to weigh one pound. We have used the same in all our tests, making in every instance two cakes of the mortar under consideration, by forming them in a circular mould or ring $1\frac{1}{4}$ inch in diameter, and $\frac{5}{8}$ inch deep. As soon as these cakes are prepared, which is done by pressing the mortar into the ring with a spatula, and smoothing off the upper surface, one of them is immersed immediately in water of an established temperature (65° F.), and the periods of time which it requires to be able to bear respectively the $\frac{1}{12}$ inch wire, weighing $\frac{1}{4}$ of a pound, and the $\frac{1}{24}$ inch wire, weighing one pound, are accurately noted by the watch. The other cake is left in the air (also brought to 65° F.), until it supports the $\frac{1}{12}$ inch wire, and is then immersed in water, and the time required to bear the small wire and heavy weight ascertained.

"Hydraulic activity" and "hydraulic energy."

Testing wires.

122. The wire test of hydraulic activity, when applied to cement paste without sand, does not furnish even an approximate indication of the relative value of mortars of the same cements when mixed with a full dose of sand; for a quick cement might contain one-half or three-fourths of its volume of inert matter ground up with it, and consequently be incapable of receiving much sand, and still be superior in hydraulic activity to another, although the latter might be entirely unadulterated and its capacity for sand unimpaired.

Wire test of pure cement paste not reliable.

Reasons why.

In pronouncing on the value of cements, from a comparison of their relative hydraulic activity, they should, therefore, be mixed with two and a half to three times their volume of sand. Even with this precaution, the result is far less reliable than some simple device for trying the strength of the mortars, when ten or twelve days old. As an evidence of the truth of this remark, it may be stated that, although eminent hydraulic activity or quickness is not necessarily accompanied by inferior hardness and strength, and conversely, neither is a slow setting cement necessarily a strong one; still, within the range of the experiments which furnish the tables of this work, it is somewhat remarkable that the quickest cements gave the worst results, and the slowest ones the best.

Large doses of sand to be used.

123. The effects of a variation of temperature upon the hydraulic quickness of mortars, whether derived from hydraulic lime, hydraulic cement, a mixture of common lime and pozzuolana, or produced by artificial means is very marked; so much so indeed, that in all comparative tests of this kind, it is important to adopt some fixed standard of temperature, not only for the water with which the cement is mixed, as well as that in which the cement is immersed, but for the dry ingredients and the surrounding atmosphere.

Effect of change of temperature on hydraulic activity.

To illustrate the necessity for these precautions, we will instance two kinds of United States cements. With the dry cement and water for mixing at 90°F., one of these cements immersed in the state of paste in water at 90° F., supported the $\frac{1}{12}$ inch wire loaded to $\frac{1}{4}$ of a pound in $1\frac{1}{2}$ minutes. The other one required 4 minutes to attain the same set. Lowering the temperatures to 65°, the former required 6 minutes, and the latter, 17 minutes; while at 35°, the respective periods were lengthened to 39 and 82 minutes, showing for a depression of 55° in the temperature of the paste (viz.: from 90° to 35°), a corresponding prolongation of the

Examples cited.

period required to set, amounting in the one case, to 37½ minutes, and in the other, to one hour and 18 minutes.

Deductions.

Hence, *all cements are not equally sensitive to a variation of temperature;* also, *those varieties which contain an excess of caustic lime may exhibit a superior degree of hydraulic activity, due to the heat generated in bringing this lime to the state of hydrate.*

124. The diagram (Figure 8) is intended to show the effect of a variation of temperature upon the time of setting of cements formed into cakes or cylinders of stiff paste, as described, paragraph 121, immersed in that condition in water.

Explanation of diagram.

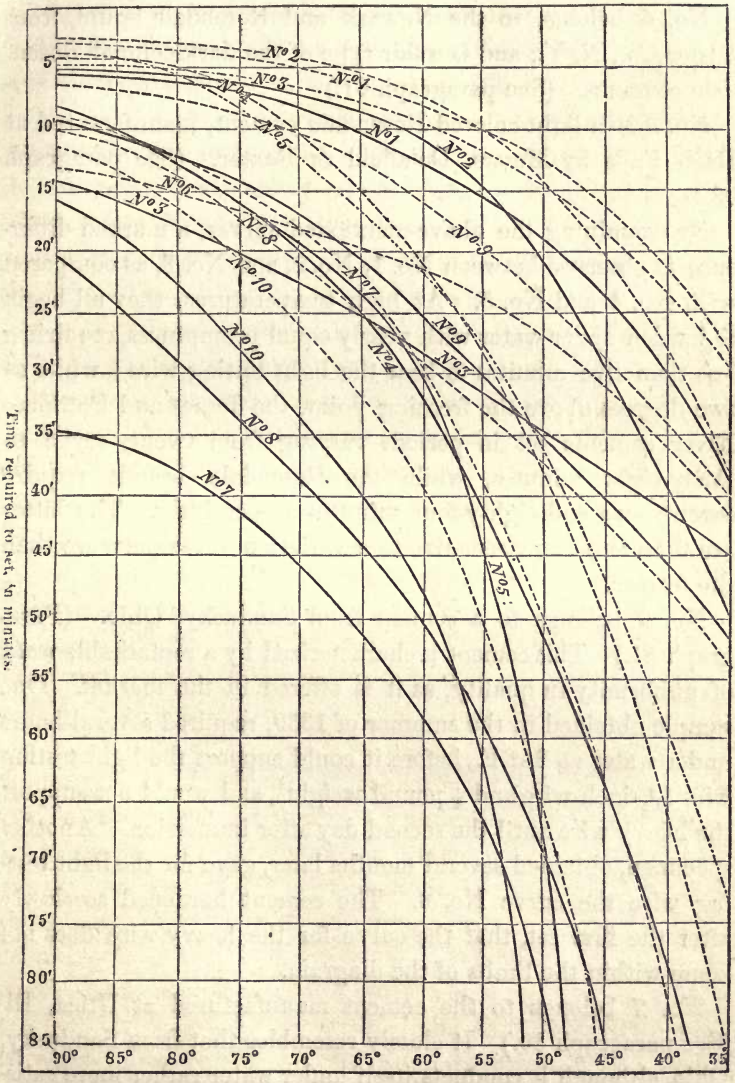
The curves are constructed with abscissas, which represent the temperature of the air, water, and dry cement (these being varied equally and kept together in all cases), and with ordinates, which represent the times of setting, in minutes, that is, the period of time which elapses before the immersed paste can support the loaded wire point without depression. The dotted curves refer to tests with $\frac{1}{12}$ inch wire, loaded to $\frac{1}{4}$ pound, and the full curves to the $\frac{1}{24}$ inch wire, loaded to one pound.

OBSERVATIONS ON THE DIAGRAM, FIG. 8.

No. 1 is from the Round Top Cement Works, on the Potomac River, near Hancock, Md. (See paragraph 75.) This is a very quick setting cement, whether left in the air, or immersed in water. For masonry, or concrete work in running water, when it is necessary to carry on operations in cold weather, the dotted curve indicates that no cement in the country is superior to it in rapidity of first induration. It sustains a change of temperature better than any cement tried, except No. 3.

No. 2 is from the James River Works, at Balcony Falls, Rockbridge Co., Va. For all temperatures above 55°, this cement exceeds in hydraulic activity, all the specimens submitted to trial; while below 48° it is surpassed by only two, the Round

Top and the Cumberland (No. 3). At all temperatures it sets in the water almost as quickly as it will in the air. (See paragraph 79.)



Temperature of water, dry cement, and air.

Fig. 8.

No. 3 is from the Cumberland cement. (See paragraph 77.) It is less sensitive to a depression of temperature than any exhibited in the diagram.

No. 4 belongs to the Newark and Rosendale brand, from Ulster Co., N. Y., and is a fair type of the dark-colored Rosendale cements. (See paragraph 61.)

No. 5 is a light-colored Rosendale cement, manufactured at High Falls by Messrs. Delafield & Baxter. (See paragraph 63.)

By examining the above-mentioned curves, a marked difference is observed between No. 1, No. 2, and No. 3, as compared with No. 4 and No. 5. At high temperatures, they all begin to harden under water with nearly equal promptness, requiring less than five minutes to bear the light testing wire; while at two degrees above the freezing point, the James and Potomac River cements set in periods varying from twenty-seven to thirty-eight minutes, while the Rosendale brands require seventy-two and eighty-four minutes respectively. The latter are therefore more sensitive to a variation of temperature than the former.

No. 6 belongs to a cement from Sandusky, Ohio. (Paragraph 81.) This cement is characterized by a remarkable want of uniformity in quality, as it is offered in the market. One sample obtained in the summer of 1859, required several hours under water at 65° F., before it could support the light testing wire ($\frac{1}{12}$ inch wire and $\frac{1}{4}$ pound weight), and would not support the heavy wire until the second day after immersion. Another specimen, obtained several months later, gave for the light testing wire the curve No. 6. The cement hardened so slowly after the first set, that the curve for the heavy wire does not come within the limits of the diagram.

No. 7 belongs to the cement manufactured at Utica, Ill (See paragraph 80.) It closely resembles that from Sandusky, Ohio, although it conducts itself under water rather more satisfactorily. By mixing the Sandusky and Utica cements to-

gether, in equal quantities, a combination is obtained, which from experiments carefully repeated on a small scale, appears to be superior to either. It is therefore suggested to Western engineers and architects to use them in this way.

No. 8 is derived from an artificial cement prepared from a stiff paste of fat lime mixed up with a sufficiency of double alkaline silicate, of 39° Baumé, in solution to bring it to the consistency of ordinary mortar. Almost any required degree of hydraulic activity may be conferred upon a paste of fat lime in this way. Limes that have been allowed to remain some days in the state of paste before adding the silicate, are preferable to those that have been slaked to a powder and preserved in that condition. These latter are apt to crack under water, after the silicate has been added.

No. 9 was from Roman cement manufactured from "Septaria," or clay nodules found on the coast of Scotland. It is proper to remark, that this cement bore evidences of having suffered from exposure during transportation, and was not therefore so fresh, and of course, not so energetic as an average sample would have been. In hydraulic quickness, fresh Roman cement is by no means inferior to the best Rosendale brands, while its subsequent progressive induration probably exceeds that of most American cement.

No. 10 is from the cement manufactured at Louisville, Ky.

Artificial Hydraulic Cement and Lime.

125. It is possible to make hydraulic mortar by using *artificial* preparations of hydraulic cement, lime, and pozzuolana, and this course is often pursued, particularly in France, in localities where there are no natural deposits suitable for such purposes. There are four methods of attaining this object, viz.:

Artificial hydraulic mortar.

Four methods of making it.

First, by combining thoroughly slaked common lime with unburnt clay in suitable proportions, burning the mixture in a lime-kiln or furnace, and

First method.

then grinding it, producing what is called twice-kilned "artificial hydraulic lime."

Second method.

Second, by substituting for the quicklime a carbonate of lime that can be pulverized without burning, like chalk, in other respects following the directions of the first process.

Third method.

Third, by making artificial pozzuolana, which is effected whenever calcareous sand and certain kinds of clay are subjected to a slight calcination.

Fourth method.

Fourth, by adding silica, in a soluble form, to a paste of common lime.

FIRST METHOD.

Drying the clay.

126. Before the calcination, the clay should be fully dried in the open air, or under sheds prepared for the purpose, after the manner of bricks and pottery. The proportion of lime and clay used should be varied according to the quality of the clay, the character and purity of the lime, and the degree of hydraulic quickness which the resulting product should possess, that is, whether it is intended to imitate hydraulic cement or hydraulic lime. Ten per cent. of clay will confer "moderately hydraulic" energy, while it will never be necessary to exceed 54 per cent. to produce a very active cement. The clays that have been found most suitable for that purpose are those which are unctuous to the touch, and are of common use for manufacturing various kinds of earthenware. They contain .30 to .50 of alumina, and .04 to .05 of carbonate of lime. It is of the highest importance that the lime and clay should be thoroughly and homogeneously incorporated with each other by means of a mortar mill, if practicable, previous to the drying process, and that this latter should be continued until no trace of humidity remains. If this last condition be not fulfilled, no good results can be obtained, as the silica contained in the clay will not be in a state

Proportion of lime and clay.

Kinds of clay most suitable.

favorable to its combination with the lime in the dry way, and the clay will remain almost entirely inert, from the moment the mixture reaches a dull red heat. These facts, originally promulgated by M. Rancourt, have been amply verified by repeated experiments conducted by M. Ducreux and others. To prepare the mixture of lime and clay for drying and burning, it is customary to cut it up into small cakes, or roll it into balls of two or three inches diameter.

Preparation of mixture for burning.

127. The calcination is effected at a lower temperature than that required by the natural stone; a bright red heat is sufficient, as water is more easily disengaged from the cakes than carbonic acid would be. It is also necessary that this second calcination should take place under the influence of a good draught, or in contact with the air. The material thus obtained is said by M. Vicat to be preferable to the best hydraulic limes directly obtained from argillaceous limestones, but we shall see further on, that this is at least doubtful. A saving of fuel can be effected by burning raw bricks, or common lime, or both, in the same kiln, with the argillo-calcareous balls, and this is practised in many countries. It can be done in kilns somewhat higher than the average, say eighteen feet, filling them with carbonate of lime up to nine and a half or ten feet, placing over it bricks to a height of five feet, and over the latter, the small pieces of lime and clay which have to be converted into hydraulic lime. The burnt balls may be pulverized between millstones, or by any other suitable means.

Calcined at a low temperature.

SECOND METHOD.

128. When a soft carbonate of lime, like chalk, or calcareous tufa, is employed for making artificial hydraulic lime or cement, it is not necessary or customary to subject it to calcination, previously to its being mixed with the clay. The reduction of both ingredients

Chalk and clay mixed together before burning.

to a fine powder by suitable machinery, however, is essential as the first step; after which they are thoroughly mixed together in proportions ascertained by previous experiments to give the desired results, made into cakes or balls, dried, calcined, and ground for use, as in the first case.

Artificial "Portland" cement.

The "Portland" cement of England and France* is made in this way, the calcination being carried to the verge of vitrification. In its manufacture, chalk is generally depended on to furnish the calcareous ingredient. The necessity of reducing the carbonate to a state of paste, and of incorporating it with the clay before any calcination takes place, practically excludes the more compact varieties of limestone. The chalk may be ground in any mill suitable for reducing such substances. One consisting of a circular trough of stone or brick work, in which two wheels are made to turn, has been used in England, and found to answer a good purpose. The wheels are located on the axis at unequal distances from the centre of motion, so as not to run in the same track. For extensive operations, a steam mortar mill like the one used at Fort Taylor (Figure 34), or some modification of it, would perhaps possess many advantages.

Chalk ground in a mill.

Chalk ground in a surplus of water.

129. Water is added to the chalk before grinding, generally in considerable surplus. After this preliminary manipulation is completed, the semi-fluid mass is conveyed into bins with grated or perforated bottoms, or made up into heaps and left, until, by drainage and evaporation, it is reduced to the consistency of stiff mortar. It is then in a condition to be mixed with the clay. *Pure alluvial clay*, or, when this cannot be procured, fine pit clay, free from sand, is next added to the chalk paste, and the thorough and homogeneous incorporation of the two ingredients is effected by means of a pug-mill. For the English "Port-

Kind of clay suitable.

* The "artificial" Portland is here referred to.

land," the argillaceous mud deposited by the Thames and Medway Rivers is used. The chalk is derived from the middle and upper layers of that formation, as it crops out on the banks of the Thames. These substances are ground up together by millstones, with a sufficiency of water to produce a semi-fluid mass. A process of decantation into vats, or hollows scooped out below the surface of the ground then ensues, by which the unground and heaviest particles are left behind.

The chalk used.

130. The mixture having attained the consistency of potter's clay, is kneaded into balls of about three inches in diameter, and dried in the air under cover for about forty-eight hours, and then burned in an ordinary lime-kiln. If the kiln be perpetual, the drawing may commence in about three days, provided a white heat has been preserved during the interval.

Mixture formed into balls; drying of balls; calcination.

131. In comparing this process with the one in which slaked lime is used, it will be observed that they differ in two essential particulars, viz.: 1st. The lime mixture must be thoroughly dried before burning, while the chalk mixture need not be. 2d. The former is calcined with a moderate or bright red heat, and the latter at a white heat. The burnt cement is ground in the ordinary way between millstones. The proportions of clay and sand in the "Portland" cement should, of course, vary with the kind and quality of the clay used.

Difference in the burning by first and second methods.

M. Vicat analyzed a sample from the manufactory of Messrs. White & Sons, with the following results:

Lime	68.11
Silica	20.67
Alumina	10.43
Oxide of iron	.87

Analysis of artificial "Portland" cement.

This composition very nearly corresponds to that of the intermediate limes.

132. The following is a synopsis of the method of preparing

Old process.

artificial cement followed in England, before the advantages of the intense heat applied in burning "Portland" cement were known.

Selection of the ingredients of artificial cement.—The chalk.—The white or upper chalk of the geologists being a tolerably pure carbonate of lime, is to be preferred to the marly or impure deposits near the surface. By mechanical means it must be reduced to an impalpable powder, or, by the addition of water, to a homogeneous paste.

Chalk.

The clay should be the *blue alluvial* of lakes or rivers, in a state of minute division, and free of sand. In England, the deposits of the Medway, and in the United States, the compact beds of this unctuous clay, and the clays used for pottery, will answer. A long exposure to the air should be avoided, as it has been found to injure the quality of the clay for artificial cement.

Clay.

Proportions of clay and chalk.—By weight, 100 pounds of pure dry chalk to 137½ pounds of fresh blue clay, being equivalent to four of chalk to five and a half of clay. *By measure*, one cubic foot of stiff chalk paste to one and a half cubic feet of fresh blue clay. Ninety-six pounds of dry chalk produces one cubic foot of chalk paste.

Proportions of chalk and clay.

Mode of grinding the chalk.—The chalk is ground with the water necessary to produce a thin paste, in a mortar mill. Colonel Pasley recommends one with two broad vertical iron wheels, on a common axle, carried around by means of a vertical shaft connected with the axle, and turning on a pivot in the centre of a cast iron pan. The wheels are placed at unequal distances from the centre of motion. The horizontal axle is attached rather loosely to the shaft, so as to allow the wheels to rise over lumps that may be larger or harder than usual.

Mode of grinding chalk.

Scrapers are attached to the vertical shaft, to remove the paste from the circumference and centre of the pan, and throw

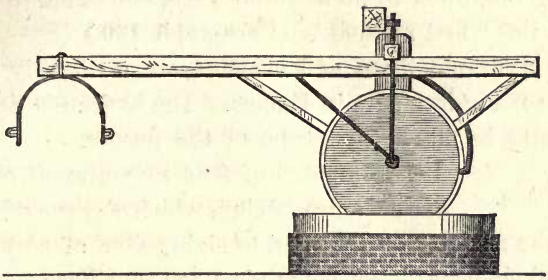


Fig. 9.

it in the track of the wheels, while other scrapers, attached to the axle, clean the sides of the wheels, as they rise out of the paste. The wheels may be four and a half to five feet in diameter, and from ten to fifteen inches wide at the rim which grinds the materials, and one of them may be placed at the central distance of eighteen inches, and the other of twenty-four inches from the centre of the pan. The radius of the horse-path may be eleven feet.

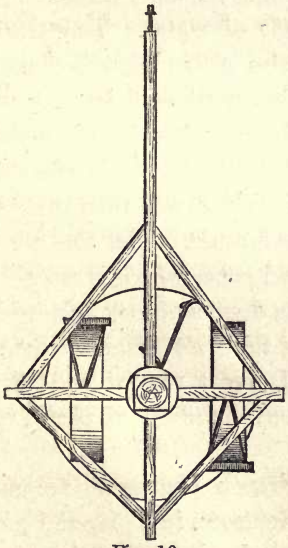


Fig. 10.

Figures 9 and 10 will sufficiently explain the general construction of this mill.

After grinding, the chalk paste will usually be found in too fluid a state for immediate use, and is generally allowed to stiffen by evaporation.

The incorporation with the clay is effected by means of a pug mill, and the mixture is then made up into balls about two and a half inches in diameter. These balls are allowed to dry under cover about forty-eight hours, or until sufficiently hard to bear their own weight when piled in the kiln for burning. The burning

Incorporation of chalk and clay.

and grinding differ in no essential particular from the process used in the "first method". (Paragraph 126.)

133. Hydraulic limes and cements are artificially manufactured in many localities in France. The hydraulic lime of St. Leger may be taken as a type of the former.

St. Leger hydraulic lime.

It is composed of four measures of chalk and one measure of clay, which corresponds, according to the analysis by Berthier, to eighty-four of carbonate of lime, and sixteen of clay containing ten of silica; or in other words, one part of clay calcined with five and a quarter parts of pure limestone. The chalk broken up into pieces of the size of three or four inches cube, is placed with the clay in a large vertical mill driven by two horses, and both materials are crushed and mixed together with a plentiful supply of water. The semi fluid mixture is then run off into a series of five troughs placed on different levels, in which it remains until sufficiently stiff to be made up into balls two to three inches in diameter.

Proportion of chalk and clay.

When these are sufficiently dry, they are calcined in an ordinary lime-kiln, and then ground up between millstones for use. The fuel used in this burning is a mixture of coal and coke, which is mingled with the balls in a perpetual kiln. The degree of heat is considerably below that required in burning the "Portland" cement.

Calcination of the balls.

For producing artificial cement, M. Vicat recommends the proportion of sixty parts of clay for one hundred of chalk, or fifty-seven of lime.

134. MM. Chatoney and Rivot, French engineers, recommended to the French Academy of Sciences, in 1856, the use of pulverized silica in combination with fat lime, for the production of artificial hydraulic limes.

Hydraulic lime composed of pulverized silica and fat lime.

These gentlemen claim that "excellent artificial hydraulic limes can be obtained, by submitting to a moderate calcination an intimate mixture of nearly pure lime and very fine sand

or ground silica, in the proportion of twenty to twenty-five parts of the pulverized silica to eighty to seventy-five of lime. The greater the care taken to produce a homogeneous mixture, the better will be the product obtained." In another place, they remark: "pulverized silica burnt with fat lime produces hydraulic lime of excellent quality. In the experiments tried at Havre within the last two years, it has set under water in three or four days, and acquired a hardness in twenty-two months equal and sometimes superior to that attained by the 'Portland' cement in one or two months." The proportions between the silica and lime were various: the weight of the powdered lime never exceeded four times, and was never less than one-half that of the powdered silica. The calcination of the mixture may be conducted according to the directions given for the clay and chalk mixtures.

Is equal or superior in hardness to Portland cement.

THIRD METHOD.

135. *Artificial pozzuolana* is produced whenever clay is subjected to a slight calcination. The properties possessed by brick or tile dust, of forming with fat lime a mixture possessing hydraulic energy, were known to the ancient Romans. Many of the feebly natural pozzuolanas have their activity very sensibly increased by burning, while there are many inert substances, besides the clays and argillaceous sands that may be converted into artificial pozzuolana by the application of a moderate heat. Forge scales, such as fall from a smith's anvil, the slags from iron foundries, the ashes from under the grates of lime-kilns, containing cinders, coal, and lime, are artificial pozzuolanas.

Artificial pozzuolana.

Feeble pozzuolanas improved by calcination.

136. It is a well established fact that nearly, if not all, magnesian, argillaceous, or argillo-magnesian limestones, of which the composition approximates to that of good cements, however destitute they

Underburnt limestones.

may be of hydraulic energy and quickness, when fully calcined, are moderately, if not eminently quick setting, if suitably underburnt. (See paragraph 264 and following.)

The same is known to be the case with pure carbonate of lime when partially burnt. Some of the coral sand from Key West, calcined for half an hour in a crucible at a bright red heat, and then pulverized, yielded a paste which attained a permanent set under water in half an hour. The tests of the strength of the mortars thus formed without sand were not very satisfactory, as compared with cement mortars. They were, however, stronger than mortars of common lime and sand, besides possessing the advantage of sustaining immersion in a short time after being mixed. There seems no reason to doubt that good artificial pozzuolanas may be produced by suitably underburning calcareous sands, and in localities where, or at times when cement cannot be had, this method of obtaining hydraulic mortar might be advantageously resorted to.

Coral sand from Key West.

Acts as pozzuolana when underburnt.

137. It must be admitted as a general fact, that all attempts to utilize the hydraulicity which characterizes underburnt *common* lime have either signally failed, or, at best, met with but indifferent success. Trials with compound limestones and certain mixed earths and sands have been more successful.

138. Some compact dolomitic earths of France have produced excellent artificial pozzuolanas. The earth is quarried by using wooden wedges, inserted and driven into notches or grooves cut in the beds, in such a manner as to favor the splitting out of good sized masses. These are divided into small blocks, dried in the sun or under a shed, and then baked in an ordinary lime-kiln. For burning, there is required about one measure of charcoal to sixteen or eighteen measures of the clay.

139. At Calais, France, a good artificial pozzuolana is produced by burning an argillo-calcareous earth taken from the sea-shore. The earth is produced by admixture, from natural

causes, of the calcareous washings of the cliffs of the Normandy coast, and the argillaceous mud either brought down by rivers, or formed by the crumblings of the upper bed of the cliffs. The earth is taken from the beach, dried and burned in the same manner as the paste of ordinary clay, in making artificial pozzuolana.

At Brest, gneiss sand is found in considerable beds. By submitting it to calcination in a reverberatory furnace, a pozzuolana is obtained, which, although not very energetic, is yet sufficiently so to cause ordinary fat lime mortar to harden in seven days.

FOURTH METHOD.

140. The fourth method, not very well understood at present, of conferring hydraulic properties upon fat lime, is strictly and technically artificial, and gives promise of more extensive application in this country than either of those above noticed. It is, besides, subservient to a variety of useful purposes in the industrial arts, to which the others could have no possible application.

Fourth method not very well understood.

It consists essentially and briefly in transferring to the lime mortar, or paste, when undergoing the last manipulation at the hands of the workman, a suitable quantity of *silica*, in such a minute state of subdivision, that it will enter into combination with the lime, in the formation of insoluble *hydro-silicate of lime*—the compound to which the cements, derived from the argillaceous limestones, principally owe the property of hardening under water.

Its prominent features.

141. The alkalies have been found to constitute a convenient and efficacious medium for this transfer. It is known that if pulverized chalk, or, in fact, any limestone in the con-

dition of fine powder, be made into a paste with an alkaline solution of silica, or what is commonly known as "liquor of flints," "soluble quartz," or "soluble glass," a chemical decomposition ensues between the carbonate of lime and the silicate of potash or soda—the carbonic acid being transferred to the alkali, whilst the silicic acid (silica) enters into combination with the lime, producing silicate of lime. These reactions take place readily under water; and the paste, thus immersed, hardens with greater or less rapidity, depending on the amount of silica used, and comports itself, apparently in all respects, like hydraulic cement. It is, in fact, an artificial stone, which, when prepared in a sufficiently liquid state, and with the proper amount of silica, possesses the property of adhering with considerable force to the surface of bodies receiving it, constituting a stony envelope, or covering, as it were, and rendering them, to a great extent, indestructible by fire or water. It is not theoretically or even practically necessary that the alkaline silicate should be in solution, when added to the lime. If employed solid, however, it must be reduced to an impalpable powder, in order to secure its thorough and complete incorporation with the pulverized carbonate, and the mixture may then be formed into a paste. Some attempts to produce artificial hydraulic mortar by this method did not give satisfactory results.

Action of the alkaline silicates with powdered chalk.

Action of paste under water.

The silicate need not be in solution.

142. If the limestone has been previously calcined, as will be generally the case in all preparations of mortar for masonry, whether of brick, stone, or concrete, and is in the condition of dry hydrate, similar results may be obtained by forming this hydrate into a paste, with a requisite proportion of silicate of soda or potash, or a mixture of both, which, as in the former case, may be either in solution or dry powder. It is believed that the advantages to be derived from a thorough and homoge-

Alkaline silicates mixed with quicklime.

neous paste can be most readily obtained, when the silica is added in solution.

143. By the means just indicated, probably the common or feebly hydraulic limes, and (what in practice will prove of greater importance) the dividing limes (*chaux limites* of Vicat), those which possess the objectionable and dangerous property of setting rapidly under water, only to be immediately followed by a gradual and complete disintegration, due to the sluggish caustic lime present, may all be transformed into reliable and valuable cements. All the initial energy of the dividing limes may be preserved in this manner.

With the hydraulic and intermediate limes.

144. Experience has shown that, if any hydraulic mortar, possessing no matter how high a degree of quickness and energy, be re-pulverized and formed into a paste, after having once *set*, it immediately descends to a level, in point of hydraulicity, with the moderately hydraulic limes. A great destruction of the hydraulic principle therefore results from any disturbance of the molecular arrangement of the mortar, after the crystallization has commenced. This is precisely what takes place in those cements denominated intermediate or dividing limes, which take the initial set promptly and firmly, but are subsequently thrown down by the slaking of the impure caustic lime which they contain.

Breaking the "set" destroys hydraulic energy.

145. The alkaline silicates supply a specific remedy for the defects just referred to, and when added in the proper form, and in sufficient quantity, to cements of this type, preserve intact all their hydraulic power, by presenting to the defective ingredient an efficacious neutralizing agent. Eight to ten per cent. of an alkaline silicate, of the consistency of thin syrup, will confer upon a mortar of fat lime a degree of hydraulicity that will place it in the class of cements in hydraulic activity, and any inferior grade of

Alkaline silicate a remedy therefor.

Proportion of alkaline silicate to be used.

energy that may be desired, is secured by proportionally diminishing the percentage of silica. To elevate the hydraulic limes to the standard of cements, or to any fixed standard, requires, of course, a less amount of silica than is necessary for the common lime, the proportion varying inversely with the active energy of the limes acted upon.

146. There is a variety of other important uses to which this silicifying process, as it may be termed, can be advantageously applied, for our knowledge of which we are chiefly indebted to M. Fred. Kuhlmann, Professor of Chemistry at Lille College, France, and M. Fuchs. We will refer to them very briefly in this connection.

147. When a solid body, of any degree of porosity, is immersed in water or any other fluid, it rapidly absorbs a certain quantity of the latter, until the point of complete saturation is reached; and if, in addition, the fluid possesses reacting powers, certain chemical changes will ensue within the pores of the solid body. If a porous limestone, like chalk, for example, or a piece of mortar of fat lime, be dipped in a solution of alkaline silicate, a certain portion of the silica in solution, after its absorption, will part with its potash or soda, and enter into combination with the lime, whilst another portion will remain mechanically interposed in the pores of the solid body, and will, in time, if exposed to a current of air, solidify by desiccation. The result will be that, with a single immersion, the density and hardness of the chalk or the mortar will be augmented, and after several alternate immersions and exposures to the air, these properties are attained in a considerable degree. The softest varieties of chalk may be thus hardened, so as to become capable of receiving a high polish.

Action of the silicate on porous limestone or chalk.

The chalk becomes harder.

148. Upon the sulphate of lime or plaster, the action of the alkaline silicate is essentially the same, though more rapid, and is accompanied by the inconvenience of giving rise to

an alkaline sulphate, which, in crystallizing within the pores of the solid body, near the surface, is apt to cause disintegration. It is recommended in this case to use the solution more diluted, with a view to retard or diminish the effects of the crystallization of the sulphate, to such a degree that the indurating solid will be able to resist it.

Action of the silicate on the sulphate of lime.

149. The process of *silicatization*, so named by Mr. Kuhlmann, which rests upon the principles enunciated above, is of undoubted utility, although, as yet, its practical application is attended with difficulties, and followed, not unfrequently, with uncertain results. It appears destined to meet with a varied and extensive application, in the industrial and fine arts, not only in the conversion, at a moderate cost, of common into hydraulic lime of any required degree of activity, and with a fair, or at least, encouraging degree of strength, but in the preservation of walls of whatever kind, already constructed unadvisedly of materials liable to more than ordinarily rapid decay, whether of brick, stone, pisé, or concrete; in the restoration and conservation of statuary, monuments, architectural ornaments, &c.; in transforming designs cast in ordinary plaster into hard and durable stone, in rendering wood-work, and, to a limited extent, even cloth fabrics indestructible by fire, and in a multitude of other collateral uses, some of which are even now well developed and in practical operation, while others remain still in their infancy, giving more or less encouraging promises of future utility and value.

"Silicatization" applicable to a variety of useful purposes.

150. Within the last ten years, grave doubts have arisen among European engineers, as to the suitability of those artificial mortars prepared by mixing slightly-burnt clay with common lime, for constructions exposed to the action of sea-water. The French engineers had entertained very favorable opinions of those mortars, and had paid great attention to their use

Doubts of the stability of *artificial* pozzuolana mortars in the sea.

between the years 1820 and 1840, deriving their opinions mainly from the investigations of MM. Vicat, Treussart, Rancourt, and others, who thought themselves justified in deducing from their results that the clays, when subjected to the proper degree of calcination, would operate in expediting the hardening of lime, in all respects like the natural pozzuolanas. For some years, these mortars exhibited no marks of weakness or instability, but more recently have, according to the opinion of MM. Chatoney and Rivot, so far yielded to the solvent action of sea-water in some localities, that but few constructors would be justified in using them, until their peculiarities are further developed by experiments and the test of time. The mortars derived from a mixture of natural pozzuolana and fat lime have been found to give better results, although it is conceded by many who have advocated the preparation of hydraulic mortar by this method, that the Romans were more successful in the employment of natural pozzuolana than those engineers who have given attention to this subject during the present century.

Authority for using them.

Natural pozzuolana mortars give better results.

151. Marshal Vaillant, member and reporter of a commission of the Academy of Sciences of France, to whom was referred a memoir of MM. Chatoney and Rivot, entitled, "General Considerations upon Hydraulic Materials used for Constructions in the Ocean," submitted to the Academy in the year 1856, says in his report, when speaking of mortars of lime and pozzuolana: "Natural pozzuolana mortars were used by the Romans for submarine constructions, which are, at the present day, in a perfect state of preservation. The Dutch engineers have likewise used them successfully in their sluice works. But all recent trials with pozzuolana, natural or artificial, have resulted in failures. According to MM. Chatoney and Rivot, these mistakes in the use of pozzuolana could, without doubt, have been avoided if,

Opinion of Marshal Vaillant thereon to the Academy of Sciences.

Recent trials with pozzuolana unsuccessful.

in conformity to the usages of the ancients, they had been previously submitted to a long concoction. Those gentlemen have as yet, no experimental results to furnish in support of this assertion, but it appears very rational. We can comprehend, in fact, that if the previous concoction is advantageous to mortars of lime, and even of cement, it is indispensable to the success of mortars of pozzuolana, which differ from the former, in that the combinations of the lime with the silica exist, for the limes and cements, already formed by the calcination, and have only to become hydrated at the time of their use; whilst, in the fabrication of mortars of pozzuolana, the silica and alumina have to free themselves from combinations in which they exist in the pozzuolana, in order to form with the lime, in the wet way, those compositions which form hydrates under water. We see from this, that it is better to mix pozzuolana with fat lime than with hydraulic lime, since in the latter case, the hydraulic compositions formed in the dry way (*voie sèche*) during the calcination, will have set a long time before those formed in the wet way (*voie humide*) become hydrates, and the setting of these latter might endanger the stability of the mortars by disintegration." Moreover, in mortars of natural pozzuolana and hydraulic lime, it is only the excess of caustic lime contained in the latter, which combines advantageously with the silica and alumina of the pozzuolana. The report goes on to say: "The artificial pozzuolanas consist of burnt clay pulverized; most of them contain lime, and possess the same causes of destruction as the mortars of natural pozzuolana and hydraulic lime. They have not yet been successful in the ocean, and their employment will always be attended with difficulty, principally on account of the irregularity of the mortars into which they are introduced.

Said opinion continued.

"The authors have had in view, in their memoir, only those mortars exposed to the action of sea-water, but they entertain the opinion that most of these observations are applicable to

mortars immersed in fresh water. Scarcely ten years have elapsed since the disintegration of mortars by the action of sea-water became a well-established fact. It was not observed until after the time when a too absolute confidence in hydraulic materials, led to the execution of *beton* (concrete) masonry in immediate contact with water, without any revetment of cut stone or carpentry, without any covering of wood, and without any of the protections which the ancient works received. It is also but a short time since *beton* has been placed in contact with currents of fresh water, and although alterations have not, as yet, taken place in that kind of masonry, nevertheless, it may be presumed that they are gradually produced by the dissolving action of the gas, and the salts which the water contains, modified by the temperature, and the action of the tides."

Said opinion continued.

152. The proposition laid down by MM. Chatoney and Rivot, that *the mortars of Italian pozzuolana, recently employed in the Mediterranean, have given unsatisfactory results*, is concurred in substantially by M. Tostain, Inspector-General of Roads and Bridges, who, in his letters written subsequently to his inspections in the years 1857 and 1858, wherein his attention had been specially directed to the condition of the mortars and concretes, observes: "I have said, and shall again say, that I saw in all the ports which I visited on the Mediterranean, in France, Algeria, Corsica, and on the coast of Italy, pozzuolana mortars attacked by sea-water. I do not say absolutely that all the mortars, without exception, were altered. There were, no doubt, good portions on which I saw nothing wrong; but everywhere, that is, at all the ports, I found partial alterations. On the other hand, I have not examined the walls of Dock No. 3, mentioned by Mr. Noel.*

Opinion of MM. Chatoney, and Rivot,

concurred in by Inspector-General Tostain.

"With regard to the portions exposed to the shock of heavy

*The dock referred to is in the harbor of Toulon.

seas, such as the large blocks of the outside works of the breakwater, I shall go further, and state that I have not seen a single one that was free from alterations, that is, one whose whole surface was intact and well preserved. The surface becomes rough at first, and is continuously made more so by the waves; the pebbles of the beton are left projecting and afterwards get loose; the edges of the work get blunt, and the volume of the block gradually decreases."

153. On the other hand, M. Noel, Inspector-General of Roads and Bridges, who takes the other side of the question, brings to the discussion a ripe experience, and a reputation by no means second to that of M. Tostain. In reference to the alleged failure of mortars of fat lime and Italian pozzuolana, he says: "This assertion is in contradiction of well-established facts. All the hydraulic works at the port of Toulon, have been executed exclusively, even of late years, with mortars composed of Italian pozzuolana and lime, either fat or hydraulic (that of Lagoubran), and I affirm with all the authority which a thirty years' residence at this port can confer, that not one of the works has failed on account of defective mortar." M. Noel also refers to the successful use of the same kind of mortar by Colonel Sauli, in the construction of the dry dock at Genoa, where it was used as concrete. A description of this dock in the "Annales des Ponts et Chaussées," for 1853, furnishes the following extract: "If the work is examined more in detail, it is found that the *beton* (concrete) which constitutes the bottom of the apron and the exterior surface of the side walls, has acquired a very great hardness in consequence of its composition, (pozzuolana of Rome, ordinary lime, and calcareous gravel), and that it is free from all porosity, in consequence of the care which the skilful director of these works took to clear his beton, by constantly pumping up the *washings* (*laitance*) during the operation of immersion."

Contrary opinion of Inspector-General Noel.

154. The mole of Algiers was executed in concrete, some

portions of which were composed of artificial blocks, allowed to dry in the air before immersion, and other portions, of concrete immersed fresh. In this connection, therefore, we will briefly refer to certain "observations and experiments upon the mortars employed in the sea at Algiers," made by M. Ravier, engineer of roads and bridges, and published in the "Annales des Ponts et Chaussées," vol. viii., 1854. From this we learn that prior to the year 1852, the mortars immersed, after drying in the air, were composed of fat lime and a mixture of equal parts of sand and Roman pozzuolana, and that the lime was slaked successively by the ordinary process, and by aspersion. In the first case, the mortar contained equal volumes of lime paste, sand, and pozzuolana, in the second $2\frac{1}{2}$ volumes of slaked lime in powder, $1\frac{1}{2}$ of sand, and $1\frac{1}{2}$ of pozzuolana. Mortars for immediate immersion were composed of fat lime and Roman pozzuolana in various proportions. Since the beginning of the year 1852, hydraulic lime from Theil, on the right bank of the river Rhone has been used, the stone being calcined at Algiers, and slaked by aspersion, as required for use. For making the mortar for the artificial blocks, it is mixed with sand. In exceptional cases, when the blocks are to be immersed at the age of thirty days, one-half of the sand is replaced by pozzuolana. An analysis of the Theil limestones is given in Table IV. Page 226.

Mortars of the mole of Algiers.

155. Without attempting a connected synopsis of M. Ravier's report, referred to in the last paragraph, a few brief extracts are given below:

1st. Page 25: "It results from the foregoing experiments, that all mortars on trial of fat lime, sand, and Roman pozzuolana, after drying in the air, or immersion in fresh water, are destroyed when placed in sea-water. This takes place even with a mortar containing by weight about twenty of caustic lime for one hundred of pozzuolana, and one hundred and thirty of sand."

Extracts from M. Ravier's report thereon.

2d. Page 29: "It follows from these observations that fat

lime mortars do not sustain immediate immersion (in sea water) no matter what proportion of pozzuolana they contain. . . . . ." "The trials were all favorable to mortars of hydraulic lime with or without pozzuolana."

3d. The trials with mortars of fat lime and Grenoble cement allowed to dry in the air, show that the cohesion of these gangs diminishes with age. A mortar composed by volume of 2.15 of fat lime, 1.00 of cement, and 5.40 of sand (corresponding with equal weights of dry cement and quicklime) gave a cohesion strength of 2.55 killograms per centimetre square, at the age of two months, and of 1.16 killograms at the age of twenty months. Another mortar, with the same proportion of sand, with a gang containing by weight 100 of dry cement and 47 of quicklime, gave at the same ages, breaking weights, 2.82 kilos. and 1.59 kilos. per centimetre square, respectively.

Strength of certain mortars.

156. The following is a condensed view of the *résumé* given by M. Ravier himself:

1st. The Roman pozzuolanas used at Algiers are, contrary to the opinion hitherto entertained, incapable of forming with fat limes, mortars able to resist the saline action of the sea-water.

2d. The form of the mortars submitted to immersion exerts an important influence upon the action of the sea-water; the sharp edges and curves of small radius assist the destructive action; plane surfaces, on the contrary, essentially protect the cohesion of the mortars, and may preserve them unaltered for several years.

M. Ravier's condensed *résumé*.

3d. The preservation of the works executed at Algiers with fat lime and Roman pozzuolana, is specially due to the deposits of mineral substances secreted by marine animals.

4th. In this respect, the artificial development of beds of oysters upon sea works, appears to promise important results.

5th. Mortars of fat lime and Naples or Rachgoun pozzuo-

lana, also fail in the sea. Similar failure attaches to the mortars of sand and St. Chamas hydraulic lime.

6th. All the observations are favorable to the perfect preservation in sea-water of mortars of sand and hydraulic lime from the Theil quarries.

The same, continued.

7th. The substitution of an equal volume of Rachgoun or Roman pozzuolana for a part or the whole of the sand, in the mortars of Theil hydraulic lime disposes them unfavorably at first, to resist the saline action. The phenomena of disaggregation that were observed were limited, and furnish no sufficient reason, without further proof, for excluding the use of pozzuolana concurrently with hydraulic limes, when it is desirable or necessary to obtain a mortar that will indurate rapidly.

8th. The Roman, Rachgoun, and Naples pozzuolanas used in the trials, are not homogeneous; the differences affecting the composition of the silicate of alumina, in each of these materials, vary between somewhat wide limits.

9th. The same want of homogeneousness is established for the limestones of the Theil and Alignol quarries, which both belong to the same formation.

10th. The analysis of the limestones of the Theil quarry, and the results obtained in the sea with the limes manufactured from them show, that by taking for the measure of resistance to the saline action, the ratio of the clay plus the magnesia to the lime, this ratio, which has been called the *index of hydraulicity*, can, on the average fall to $\frac{3.6}{100}$, without the mortars being destroyed, whether they were immersed dry or fresh.

The same, continued.

11th. The disaggregation of the mortars coincides with the increase in the quantity of the sulphate of lime, and must be attributed to that salt, produced by the action upon the lime, of the sulphate of magnesia of the sea-water. It was produced in variable proportions in all the gangs experimented upon, but destroys

them only in the cases when it is produced in sufficient quantities. The surfaces upon which this salt exists abundantly, can acquire and preserve a considerable hardness.

12th. In the mortars of fat lime and Roman pozzuolana, the sea-water attacks not only the free lime, but also that combined with the silica.

13th. In the mortars of hydraulic lime preserved intact, after having been kept under water for several years, and also in the gangs of Vassy cement, a notable proportion of free lime is detected.

157. M. Féburier, as the result of numerous experiments at St. Malo upon various limes, pozzuolanas (natural and artificial), and trass, arrives at the following conclusions, which, although indorsed by M. Vicat, are by no means coincident with the deductions of other eminent French engineers:

M. Féburier's experiments.

1st. "That mortars of fat lime and Dutch trass do not resist the action of sea-water."

2d. "That ordinary artificial hydraulic limes, or natural feebly hydraulic limes, even when mixed with feebly hydraulic pozzuolanas, equally do not resist."

3d. "The only limes capable of thus resisting are the 'twice kilned' artificial hydraulic limes, or the natural hydraulic limes which approach the limits of cements."

His conclusions

These conclusions are irreconcilable with the excellent results obtained by the Dutch engineers with mixtures of rich shell-lime, trass, and sand.

158. There seems no reason to doubt that the natural quick-setting cements, such as the Roman, the Vassy, the Rosendale, and the Boulogne "Portland" brands, and those artificial Portland cements, produced by calcining a mixture of chalk and clay with a heat sufficiently great to produce incipient vitrification, can furnish mortars capable of resisting the solvent action of sea-water.

159. Upon the general question of the destructive effects of sea-water upon those gangs, natural or artificial, which form the bases of hydraulic mortars, whether derived from hydraulic lime, cement, or pozzuolana, M. Vicat's researches led him to certain conclusions which may be condensed as follows, from the "Annales des Ponts et Chaussées" for 1854:

1st. The double hydro-silicates of alumina and lime are devoid of stability, and will, without exception, if pulverized and immersed in sea-water, or even pure water, before they have been subjected to the action of carbonic acid, and thereby transformed to carbonates, give up to the water an appreciable quantity of lime.

M. Vicat's views.

2d. The other conditions remaining the same, a dilute solution of sulphate of magnesia substituted for the *pure* water, will convert all the lime of these silicates into a sulphate, unless carbonic acid be present during the reaction, in which case its equivalent of lime will become a carbonate.

3d. All pozzuolanas, irrespective of origin or composition, require for their complete practical saturation a much smaller dose of lime than they generally receive, when made into mortar, owing to imperfect pulverization and manipulation.

4th. The affinity of carbonic acid for the lime is sufficiently powerful, in the presence of water, to separate its full equivalent of lime from combination with the other ingredients of these silicates, leaving the said ingredients, whether combined or not with each other, simply mixed mechanically in the compound.

Same, continued.

160. From the foregoing it would appear that sea-water will destroy the gangs of all mortars derived from the sources indicated, if it be allowed to penetrate the immersed masses; but as some mortars do practically withstand continuous immersion in sea-water, it follows that the latter meets on the surface something to impede or prevent its penetrations. These impediments are:

Protecting coat.

1st, and principally, a coating of carbonate of lime; the car-

bonic acid being supplied from the atmosphere before immersion, and subsequently from the water;

Carbonate of lime.

2d, in certain cases, particularly with gangs derived from the magnesian limestones, the formation of carbonate of magnesia.

Carbonate of magnesia.

3d, an incrustation of shells and submarine vegetation.

161. M. Vicat was subsequently led to recommend magnesia as a suitable ingredient of mortars to be immersed in sea-water, stating that if it could be obtained at a cost that would permit its application to such purposes, "the problem of making *beton* (concrete) unalterable by sea-water would be solved." That learned experimenter also intimates that the Theil hydraulic lime is the only one with which he is acquainted, that could unquestionably furnish a mortar indestructible by sea-water. M. Balard suggests that the mother water of salt ponds, applicable to no other useful purpose, might supply magnesia at a moderate cost.

Magnesia recommended.

Suggestion by M. Balard.

162. In the presence of these conflicting opinions, which are characterized by apparently irreconcilable elements, the American engineer can congratulate himself that the supply of hydraulic cement in this country affords a more reliable source of hydraulic mortars than either natural or artificial pozzuolana; and that this question, therefore, possesses for him no important practical bearing.

American cement mortars.

CHAPTER V.

163. Our nomenclature of the products derived from the calcinations of the several varieties of limestone, still remains imperfect.

164. These products are as varied and diversified in their character, and require as many distinct and peculiar modes of manipulation, in order to satisfy the conditions which are indispensable to their advantageous employment for mortar, as there are variations in the composition of the limestones themselves. This is more especially the case with those limestones which contain so large an amount of foreign matter, such as silica, alumina, magnesia, etc., usually exceeding ten of the whole, as to disqualify them for ordinary use as fat lime, but which places them in the category of hydraulic limes or cements. When we keep in view the multiplicity of causes for such variation in all sedimentary rocks, causes, indeed, that pertain in their fullest force to all calcareous formations, and more especially to those which, from their compound character, have proved to be best adapted to the production of hydraulic mixtures, we obviously need seek no further for an explanation of that remarkable want of homogeneousness which characterizes these deposits, or expect to find any locality in which it does not exhibit itself.

Diversified character of limestones.

165. The same strata, even within very narrow lateral limits, frequently become so changed in their physical appearance as well as in their chemical composition, as to lose not only the means of verifying their geological identity, but their most prominent lithological features.

166. We might, therefore, expect that the best practical rules for converting such heterogeneous material into use as a gang for mortar, would require to be modified to suit local circumstances. It is equally self-evident that such modifications can only be properly determined by adequate preliminary and local tests. Although the theoretical correctness of these premises will perhaps be questioned by very few, their practical observance by manufacturers and consumers of limes and cements, is greatly neglected.

Local examinations and tests necessary.

167. The calcareous deposits in the United States, from which the present supplies of lime and cement are derived, if severally classified and arranged according to their composition, as shown by quantitative analyses, would strikingly illustrate the necessity of awarding to each locality such special rules for manipulation as can only be supplied by an extended series of experiments. It is not to the almost endless variety of quarries of dissimilar stone simply, that the difficulty is confined, since this, however great, is only coextensive with the extraordinary heterogeneity generally existing among the strata of the same quarry. Although this feature does not characterize the beds of common limestone, at least, not to an extent that can be regarded as prominent, it is so uniformly present in the argillo-magnesian deposits, that we may safely assume that every extensive deposit capable of furnishing an energetic cement, will also furnish from among its several layers, every inferior grade of combination, down to slightly hydraulic, meagre, and common lime.

Heterogeneity of cement deposits.

168. Frequently, and perhaps generally, among deposits furnishing cement stone, the several layers—which vary considerably in thickness, though they are seldom less than one foot or more than six—so far preserve the character and relative proportion of their constituent parts within the ordinary lateral limits of a single quarry, as to require only an occasional,—it may be a semi-weekly, or weekly, or perhaps, in rare cases, a

monthly,—verification of their respective characters, but in a majority of cases, the want of homogeneousness extends to the several layers individually, and attaches to them persistently for miles in extent, rendering it necessary to keep a daily, and even hourly surveillance upon the workmen, to prevent their making use of bad or worthless stone.

A general and persistent feature.

169. When the stone occurs in distinct and easily recognized layers which, for considerable distances, retain with little variation, a known and specific character, whether good, bad, or doubtful, and which are readily separated from each other along the principal planes of subdivision, the practical difficulties to be overcome in quarrying are comparatively few, and simply require for their removal, the employment of reliable and faithful workmen, who will exercise the precaution to reject those strata which are known to be unfit for use.

170. In the general case, however, the problem is far less easy of solution, for we find those materials, whose exclusion from the combination is of the highest importance, disseminated throughout a series of strata, in constantly and widely varying proportions, and frequently in a form presenting no physical features except to the most practiced eye, to assist in their detection. The calcination sometimes so far alters their appearance, as to render them more easily identified. These materials generally consist of carbonate of lime more or less pure; or a compound stone, in which the preponderating ingredient is inert silicious sand; or argillaceous slate or limestone, containing an excess of clay and granulated silica. They usually occur in rather thin masses or sheets, varying from two or three inches to several feet in length and breadth. There is probably not a single quarry in the United States, worked for hydraulic lime or cement, entirely free from them. For the detection and exclusion of these objectionable portions of a quarry, we must, therefore, depend

Practical difficulties in selecting good stone.

The ordinary precautions necessary.

conjointly upon the faithfulness of the quarryman, the experience of the burner, and his skill in detecting them after calcination.

171. Changes in the character of a cement stone often take place slowly and progressively within the limits of individual beds, in directions both perpendicular and parallel to the planes of stratification, without any perceptible variation in the appearance of the stone, or in its homogeneousness, and simply require for their correction a modification in either the *proportion* of the different layers introduced into the combination, in the *degree* of calcination to which they are subjected, or in *both*. It might, under such circumstances, become necessary to use separate kilns for layers that had previously been mixed together in burning. Deposits of this character require close and constant attention, in order that the proportion of the several dissimilar layers, and the intensity and duration of the heat employed in burning them, may be so regulated as to give results that shall be uniform, or at least approximately so.

Calcination of dissimilar stone.

172. It is therefore important that some practical method of ascertaining the absolute as well as the relative value of these several kinds of stone, should be pointed out, and it is equally important that such a method should be simple, inexpensive, and easy of application. It is not necessary, though it might be advantageous in some cases, that it should comprise any essay upon the composition of the stone, or the proportion of its constituent parts. Indeed, any practical method would be much better without any accessory requiring the exercise of any theoretical knowledge, not within the ready comprehension of that class of men to whom manufacturers, with few exceptions, confide the details of their work, and consequently not susceptible of daily and hourly application by them.

Preliminary trials recommended.

173. The only apparatus required for this purpose is a crucible of the capacity of one pint or thereabouts, and a mortar and

pestle. The crucible should be perforated near the bottom, in several places, to give an upward current of air and facilitate the escape of carbonic acid gas, and should be provided with a cover likewise perforated. When access can be had to a grate fire of anthracite coals, this single crucible may be advantageously replaced by several of smaller size. When more than one is used, however, care must be taken to so regulate the fire, that all will be subjected to an equal degree of heat throughout the burning.

Details of their character.

One or more crucibles required.

174. The stone to be tried, after being broken into pieces as nearly equal in size as possible, and not exceeding three-quarters of an inch cube, is introduced into the crucibles, supposing several to be employed, each receiving the same number of fragments, if practicable. All the crucibles, with the covers on, are then imbedded in the fire and covered up with coals, so that the top and bottom portions will attain a bright red heat simultaneously. This last precaution is essential to the complete success of the process. In about forty-five minutes after the stone has reached a bright red heat, one of the crucibles is removed from the fire, the others following in succession at intervals of forty-five minutes. In order to secure similar results with a single large crucible, two or three of the fragments are taken out at the end of the first forty-five minutes of bright red heat, and others subsequently, as the periods of time above designated are reached, allowing not less than four and a half hours to the last portions, or perhaps six hours, should the stone be very refractory, which will be sufficient to expel all the carbonic acid gas, and to carry some varieties of cement stone, if broken up as directed, to the point of incipient vitrification.

Stone broken into equal-sized pieces.

Heated simultaneously.

Pieces removed at equal intervals of time.

175. A long-continued bright red heat operates in a singular manner upon some argillaceous varieties of cement, border-

ing on the intermediate limes, in conferring upon them remarkable hydraulic properties and energy, which they do not possess at the point of complete calcination, but which may have been present in a lower degree before all the carbonic acid was expelled. In order to render certain the detection of stone possessing this property, when its presence is suspended, it is recommended to continue the calcination of some of the fragments for eight or nine hours.

Long continued heat sometimes best.

176. By means of the several aforementioned crucibles, we obtain portions of the stone that are overburnt, other portions that are insufficiently burnt, and an intermediate class, among the several members of which will be discovered good cement, if the stone be capable of yielding it. There will also be indicated, to an extent sufficiently exact for practical deductions, the relative degrees of calcination adapted to the several varieties operated upon, with their exact and appropriate maximum limits, respectively. These specimens, unless the stone belongs to some grade of common, meagre, or hydraulic limes, will not slake when sprinkled with water. Upon being separately reduced to powder in a mortar, mixed to a stiff paste with fresh water, and immersed in water either fresh or salt, they will indicate in their respective times of setting, their relative hydraulic energy, and approximately,—though subject to many individual exceptions in regard to the ultimate strength of the gangs,—their value as cements.

177. Whether the stone be suitable for cement, or otherwise, it will be found, with very few if any exceptions, that the underburnt fragments, those which contain in the centre a small core of partially raw stone, as indicated by its density, color, and hardness, and which effervesce briskly with dilute hydrochloric acid, will be superior in hydraulic activity to the more highly calcined samples, and will set under water at 65° F., in periods varying from five to fifty minutes. Those which do not effervesce with dilute acid, and have consequently parted with all their

Underburnt stone possesses superior hydraulicity.

carbonic acid gas, will exhibit a less degree of hydraulic quickness, and will require a longer time by twenty-five to fifty per cent. to harden under water; while the overburnt samples, those in which the calcination has proceeded to the verge of vitrification, will, in some instances, be almost entirely wanting in hydraulic activity, and in others, will have this property very much impaired. It by no means follows that this last-mentioned class is inferior to the others in the ultimate energy and strength of its gangs or mortars; on the contrary, some cements, the "Portland" for example, are much improved by this degree of burning. Others, however, are rendered entirely worthless by it, so that M. Petot's assertion that "it is equally possible to obtain plastic (that is hydraulic) cements by a super-calcination, and by an incomplete calcination," must be received in a modified sense. Petot further remarks, that the fact most worthy of notice is, that at the point of *complete calcination* not only will "the stone not slake, but if treated like ordinary cement, will give a substance nearly inert." "This instant of inertia of plastic cements, between the points of incomplete calcination and supercalcination, seems to us a capital fact in the study of the substances. It explains how a suitable limestone might escape discovery and be rejected as unsuitable, from a simple fault of calcination, which would not be a fault with fat lime, or with hydraulic lime."

Some overburnt varieties nearly inert.

The same not necessarily of inferior strength.

Remark by M. Petot. Alleged "instant of inertia" of cements.

178. In point of fact, there is no such "*instant of inertia*" invariably existing between two points of maximum energy, in genuine cements. It may or may not be the case, according to the composition and molecular constitution of the stone. Moreover, some cements have three points of maximum energy, while others have but one. Those which possess one, in a pre-eminent degree, at the point of vitrification, generally approximate to the intermediate limes in the nature

Does not invariably exist.

M. Petot's deduction altogether too general.

and proportion of their constituent ingredients. M. Petot seems to have made general a deduction, on evidence drawn from a particular case only, and to have simply opened, far less exhausted, the investigation.

179. M. Vicat's opinion that a complete expulsion of the carbonic acid gas, although operating disastrously upon the intermediate limes, is necessary in order to fully develop the merits of genuine cements, must also be discarded as a rule, although individual cases in support of it are by no means rare.

Same, of M. Vicat's opinion.

180. If none of the samples from the crucibles, except those that are considerably underburnt, set under water, without being followed by cracks, disintegrations, or increase of volume, the stone belongs to that class termed intermediate or dividing limes, already mentioned, and should be rejected with scrupulous care, unless provision can be made for burning it by itself, and for arresting the calcination at the proper time.

Treatment required for intermediate limes.

181. By carefully subjecting, from time to time, the several undivided layers of a quarry to the trials above indicated, taking care to secure a faithful fulfilment of all the conditions specified, so that each will receive precisely the same treatment, we are able to ascertain with sufficient accuracy, and to keep constantly in view, the peculiar character of each kind of stone; such as its appearance when properly calcined; the requisite degree and duration of heat; the correct limits of calcination; and consequently the best mode of burning it on a large scale (whether by itself or mixed with the other layers), and the most advantageous proportions in which it should enter into a combination of the whole.

182. Experience teaches us that the physical appearance of calcareous stones, which sufficiently serves to distinguish and classify them, when in the natural state, into limestone and marbles of various kinds, furnishes no indication of their qualities after

Physical appearance of raw stone no criterion of its properties.

calcination. Even a chemical analysis of the raw stone is to a certain extent unreliable, and deductions from it, under the most favorable circumstances, can only be regarded as tolerable approximations, and are not unfrequently contradictory. The hydraulic induration is due, in a great measure, to the chemical combination of lime and silica, a union which is partially perfected in the dry way during the burning, and is subsequently carried on and completed by the agency of water. The analysis of a cement stone after calcination, should therefore show the commencement of this process by the presence of a certain quantity of silicate of lime.

Source of hydraulicity.

QUALITATIVE EXAMINATION OF HYDRAULIC LIMESTONES.

183. Hydraulic limestones are characterized, as a class, by their fine-grained, compact, or granular texture, presenting a conchoidal fracture, yielding readily to a file or sharp-pointed instrument, and effervescing more or less freely, on the application of hydrochloric or nitric acids.

Mineral characters.

184. The prevailing colors are gray, bluish gray, grayish white, and drab, with intermediate shades.

185. The powdered mineral is more readily acted on by the acids than the massive form.

186. Hydraulic limestones will generally be found to contain *silica*, *alumina*, *oxide of iron*, *oxide of manganese*, *lime*, *magnesia*, *potash*, *soda*, with *carbonic*, *sulphuric*, and *phosphoric acids*, and occasionally some organic matter of a bituminous nature. As some of these may be absent, it will be necessary to ascertain the character of those present, before proceeding to an ultimate qualitative analysis.

187. For this purpose, an unweighed portion of the mineral is reduced to a fine powder in an agate mortar, and digested in one measure of water, for eight or ten hours, aided by the gentle heat of a sand-bath,

Preparation.

and the solution is then to be filtered clear, and divided into so many equal portions in wine glasses.

188. *Nitrate of baryta* added to one of these gives a white precipitate, which does not disappear on the addition of nitric or hydrochloric acid, and indicates the presence of *sulphuric acid.* Sulphuric acid.

189. By evaporating another portion to *dryness*, in a sand-bath, at a gentle heat, and igniting the residue, subsequent addition of hydrochloric acid, followed by diluting with an excess of water, will cause the *silica* to separate as a gelatinous hydrated precipitate. Silica.

190. If another portion be treated with pure water of ammonia, and gives a pure white gelatinous precipitate, it indicates the presence of *alumina*, or *magnesia*, or both.

In this case, hydrochloric acid must be added, until the precipitate is re-dissolved, and the solution rendered distinctly acid. If, on the addition of ammonia, the precipitate reappears undiminished in quantity, it contains *alumina* only; if it be distinctly less in quantity, we may infer the presence of both *magnesia and alumina;* but if no precipitate now appears, it contains *magnesia* only. Alumina and magnesia.

191. If the precipitate above by ammonia has more or less of a brown color, the presence of *oxide of iron* or *manganese* may be inferred; but, if after re-dissolving and adding ammonia as above, the brown color disappears, it is due to the *oxide of manganese* only. Should the brown color still continue, it is owing chiefly to the presence of *oxide of iron.* Oxides of iron and manganese.

192. If, after the addition of ammonia, the solution be filtered to remove the magnesia, alumina, the oxides of iron and manganese, *oxalate of ammonia* be added to the filtrate, causing a white precipitate, it indicates the presence of *lime.* Lime.

193. If *oxalate of ammonia* be added, until all the lime be

Potash and soda.

precipitated, and then filtered, and the filtrate be evaporated to dryness, and ignited to destroy the excess of oxalate of ammonia, the residue if found to be soluble in water, indicates the presence of *potash*, or *soda*, or both

Potash.

194. If upon treating the last solution with pure bi-chloride of platinum, no precipitate appears, we may infer the presence of *soda;* but if a yellow precipitate appears, *potash* is present in the solution.

195. The yellow precipitate of potash and platinum having been collected on a filter, the filtrate treated with sulphide of hydrogen, and again filtered, to separate the excess of bi-chloride of platinum, and then evaporated to dryness, a residue soluble in water remaining, indicates the presence of *soda.*

Phosphoric acid.

196. Returning to one of the original wine glass solutions, to which a portion of strong nitric acid must be added, if it be then dropped into a solution of *molybdate of ammonia*, and a yellow precipitate appears, it indicates the presence of *phosphoric acid.*

Bituminous matter.

197. The presence of bituminous matter is shown by the odor or loss of weight upon igniting a specimen previously dried at 212°F.

QUANTITATIVE EXAMINATION OF HYDRAULIC LIMESTONES.

198. It is usual, in conducting this process, to ascertain:

Programme.

1st. The specific gravity. 2d. The amount of hygrometric water. 3d. The amount of phosphoric acid. 4th. The amount of silica and insoluble matter. 5th. The amount of alumina. 6th. The amount of oxide of iron. 7th. The amount of oxide of manganese. 8th. The amount of carbonate of lime. 9th. The amount of sulphuric acid. 10th. The amount of potash and soda. 11th. The amount of carbonate of magnesia.

199. The specific gravity of the specimen to be analyzed having been determined, a portion of the mineral is reduced to

fine powder in an agate mortar, and a given quantity, say 50 grains, is placed in a platinum crucible previously counterpoised with its cover. The crucible and its contents are then to be placed in a steam bath oven, and heated for two hours, when it is to be cooled in a receiver over sulphuric acid, and then quickly weighed. The loss in weight is the weight of the uncombined water. Hygrometric moisture.

200. The contents of the crucible must then be transferred to a beaker glass, and digested in strong nitric acid, to which a little hydrochloric acid has been added, for forty-eight hours, the action being favored meantime by the gentle heat of a sand bath. Phosphoric acid.

201. At the termination of this process, the solution is to be filtered, an excess of molybdate of ammonia added to the filtrate, and the whole evaporated nearly to dryness.

202. During the process, the chlorine of the hydrochloric acid, aided by the excess of nitric acid, decomposes the ammonia of the molybdate of ammonia, and the molybdic acid goes down with the phosphoric acid, as *phospho-molybdate of ammonia*, in the form of a yellow precipitate, with the formula: $2\,(3NH_4O.PO_5) + 15(HO.4\,MoO_3)$. This precipitate is insoluble in water and in nitric acid. After diluting the mixture, and giving it time to settle, the precipitate is collected on a filter, washed in pure cold water, and while yet moist, dissolved in ammonia (the beaker glass being rinsed with the latter, and added thereto). Phosphoric acid.

203. From this solution in ammonia, sulphate of magnesia precipitates all the phosphoric acid as *ammonia phosphate of magnesia.* This is to be washed with dilute water of ammonia, collected on a filter, dried, ignited at low red-heat, and weighed, —the filter having been burnt, and the ashes added to the rest.

204. Deducting the weight of the filter, every 100 grains of phosphate of magnesia thus obtained, contain 64.06 grains of *phosphoric acid;* every 100 grains of phosphoric acid may represent 217.60 of phosphate of lime.

205. This determination of *phosphoric acid* being an *independent* process, the filtered solution left above is thrown away, and, as in the start, a new solution must be prepared.

Remark.

206. Fifty grains of the same mineral prepared and dried as before at 212°, are now to be dissolved in strong hydrochloric acid, the action being favored by the gentle heat of a sand bath for forty-eight hours, after which, the solution is to be diluted with water, filtered,—and the *silica* and *insoluble silicates* washed, dried, ignited, and weighed, are recorded.

Silica and insoluble silicates.

207. The filtered solution from the preceding is then precipitated by strong ammonia, and the precipitate, consisting of *alumina*, *oxide of iron*, and *phosphates*, after being well washed, is transferred while moist, filter included, into a strong solution of pure potash, which dissolves out the *alumina*.

Alumina.

208. This potash solution, filtered from the oxide of iron, &c., is rendered acid by the addition of hydrochloric acid, and the *alumina* is then thrown down by an excess of ammonia, with a little sulphide of ammonium.

209. The precipitate thus obtained is washed with hot water, dried, ignited, and weighed. Deducting the weight of the filter, we record the absolute weight of the *alumina*.

210. The oxides of iron and manganese remaining from the potash solution, are dissolved from the filter in hydrochloric acid, the solution *carefully* neutralized by ammonia, and then, upon the addition of succinate of ammonia, succinate of iron is precipitated.

Oxide of iron.

211. Upon filtering this, and adding ammonia to withdraw the succinic acid, the residue is washed, dried, ignited, weighed, and the weight of the *oxide of iron* ascertained.

212. To the preceding filtrate concentrated to a small bulk by evaporation, sulphide of ammonium is added, causing a precipitate of sulphide of manganese. The latter, collected on a

filter, washed, dried, and *thoroughly roasted*, changes the sulphide into *oxide of manganese*, which is then weighed. Oxide of manganese.

213. Return now to the first filtrate, caused by the addition of ammonia to the original acid solution, and which contains the lime, magnesia, and sulphuric acid, simultaneously. With the processes described, Lime. we precipitate the lime by *oxalate of ammonia*. Collect it after eight or ten hours repose, on a filter, and weigh it; deducting the ashes of the filter, the weight of *carbonate of lime* is known. Every 100 grains contain 44 of lime.

214. The filtrate now contains a quantity of oxalate of ammonia, and ammoniacal salts, to decompose which pure nitric acid is added in excess, and the filtrate evaporated to dryness. Redissolve the residue in hydrochloric acid, to which an excess of nitric acid has been added, and again evaporate to dryness. This dried residue of nitrates is now *drenched* with pure acetic acid, and then washed with water. Upon the addition of *acetate of barytes* to the solution, the *sulphuric acid* present is precipitated as *sulphate of barytes*, which is collected on a filter, dried, and weighed. Sulphuric acid.

Every 100 grains contain 34.31 of *sulphuric acid.*

215. The filtrate from the sulphate of barytes is now evaporated to dryness, and transferred by a little oxalic acid and water into a small porcelain crucible, in which it is heated, and again evaporated to dryness, with an excess of pure oxalic acid, which changes the nitrates into oxalates.

216. The dried residuum thus obtained contains the alkalies and the magnesia, and must then be perfectly ignited, to change all the oxalates into carbonates. In order to separate the *alkalies* from the other ingredients in this last residuum, it is dissolved and thoroughly washed through a filter with water. The dissolved carbonates contained in the filtrate are changed into chlorides by the aid of a little hydrochloric acid, and then, evaporating the filtrate to dry- Alkaline chlorides.

ness and igniting, the saline residue is weighed, and the weigh of the alkaline *chlorides of potassium* and *sodium* recorded.

217. Redissolving the mixture of alkaline chlorides in a small quantity of water, a solution of bi-chloride of platinum is added, and the whole of the chloride of potassium present is changed into the double chloride of platinum and potassium, appearing as a yellow, insoluble precipitate.

Potash.

218. Being evaporated by a gentle heat to near dryness, weak alcohol is added to dissolve the chloride of sodium, and any excess of the platinum salt which may be present. The yellow powder is collected on a filter, washed well with alcohol, dried, and weighed.

219. Every 100 grains indicate the presence of 19.31 of *potash*, or 30.51 of the *chloride of potassium*.

Soda.

220. The weight of the chloride of potassium thus obtained, deducted from the weight of the mixed alkaline chlorides, gives the weight of the *chloride of sodium*.

221. Every 100 grains of the latter indicate the presence of 53.17 of soda in the limestone.

Magnesia.

222. The *magnesia* which remains in the portion of the residuum which is insoluble in water, is now dissolved on the filter in diluted sulphuric acid, and after evaporating and igniting in a platinum crucible, is weighed as *sulphate of magnesia*.

223. Every 100 grains contain 33.33 *of magnesia*; 100 grains of *magnesia* indicate 210 of *carbonate* of *magnesia*.

224. It will be perceived by the foregoing process, that with the exception of the moisture, organic matter, and *phosphoric acid*, which we estimated in a separate quantity of the limestone, all the ingredients have been determined from a single weighed portion, and thus a check over the whole is secured; for if the sum of the weight, of all the ingredients varies much from the 50 grains of limestone used at the outset, it is proof of errors in the process.

225. Should the amount of *silica* and *insoluble silicates* be large, they should be fused with three times their weight of carbonate of soda, for three or four hours, by which they may be brought into a soluble condition, and the solution treated as in the foregoing, and the sum of the weights ascertained.

TABLE IV.

226. ANALYSES OF HYDRAULIC LIMES, CEMENTS, TRASS, AND POZZUOLANA.

	Specific gravity.	Carbonic acid.	Potash.	Soda.	Silica, clay, and insoluble silicates.	Silica.	Alumina.	Oxide of iron.	Peroxide of iron.	Carbonate of iron.	Carbonate of lime.	Lime.	Carbonate of magnesia.	Magnesia.	Sulphuric acid.	Chloride of potassium and sodium.	Phosphates, &c.	Brown oxide of manganese.	Hygrometric water lost at 212° F.	Water and loss.	Excess (−) or loss (+).
1	2.652	.....	.62	.88	95.20	.....	6.16	.....	2.02	....	58.84	.....	.....	10.38	.48	.....	.....	.....	.40	.....	− 4.98
2	2.678	.....	.40	12.10	19.66	.....	3.14	.....	3.86	....	40.54	.....	.....	17.98	.72	.....	.....	.....	.38	.....	+ 1.22
3	2.680	.....	1.54	4.64	24.74	.....	16.74	.....	6.30	....	41.80	.....	.....	4.10	2.22	.....	.....	.....	.60	.....	− 2.68
4	2.753	.....	....	.....	17.84	.....	4.60	.....	1.70	....	58.25	.....	11.16	....	.74	3.26	.....	.....	.20	.....	+ 2.25
5	2.844	.....	....	.....	18.52	.....	2.18	.....	1.86	....	43.30	.....	26.04	.....	1.96	4.24	.....	.....	.20	.....	+ 1.70
6	2.735	.....	....	.....	29.34	.....	5.74	.....	1.76	....	33.54	.....	20.80	.....	1.02	5.80	.....	.....	.16	.....	+ 2.04
7	2.806	.....	....	.....	39.74	.....	6.00	.....	1.44	....	30.74	.....	14.48	.....	.66	7.42	.....	.....	.24	.....	− .72
8	2.822	.....	....	.....	19.64	.....	1.52	.....	2.38	....	30.72	.....	35.10	.....	.64	4.10	.....	.....	.18	.....	− .28
9	2.793	.....	....	.....	26.00	.....	4.64	.....	1.86	....	28.48	.....	32.86	.....	1.18	4.72	.....	.....	.26	.....	.....
10	2.788	.....	....	.....	28.08	.....	5.72	.....	5.38	....	43.32	.....	14.52	.....	1.60	2.78	.....	.....	.20	.....	−1.60
11	2.761	.....	....	.....	18.46	.....	4.22	.....	2.32	....	37.50	.....	35.62	.....	.20	1.68	.....	.....	1.40	.....	−1.40
12	2.786	.....	....	.....	27.70	.....	2.34	.....	1.26	....	46.00	.....	17.76	.....	.26	4.02	.....	.....	.22	.....	+ .44
13	2.790	.....	....	.....	11.10	.....	2.52	.....	1.42	....	40.00	.....	39.04	.....	.22	4.06	.....	.....	.26	.....	+ 1.38
14	2.793	.....	....	.....	19.80	.....	4.40	.....	.76	....	33.90	.....	34.06	.....	.32	4.78	.....	.....	1.56	.....	+ .42
15	2.781	.....	....	.....	33.80	.....	3.96	.....	.88	....	35.60	.....	19.26	.....	.50	6.18	.....	.....	.14	.....	− .32
16	.....	....	.0333	....	.....	20.7	...	1.7	...	.....	....	53.3	.....	22.6	.....	.....	.....	.....	.....	1.666	.....
17	.....	....	.3	....	.....	27.1	...	1.5	...	.....	....	65.0	.....	5.3	.....	.....	.....	.....	.....	.8	.....
18	.....	.....	.....	.....	.....	14.0	5.7	.....	.....	11.6	63.8	.....	1.5	.....	.....	.....	.....	.....	.....	3.4	.....
19	.....	36.28	....	.....	.....	.. 14.90 ..		.... 1.70	.....	.....	45.63	.....	.39	.....	.....	.....	.....	.....	.....	Water & Bitumen 1.10	....
20	.....	8.00	....	.....	.....	18.20	1.20	..... .80	.....	.....	60.00	.....	1.32	.....	.....	.....	.....	.....	.....	10.48	.....
21	.....	30.400	.120	.....	.....	34.225	7.800	.....	.....	.....	17.380	.....	9.513	...	.....	.....	.....	.....	.....	Water and organic matter. .500	+.062
22	.....	.....	.....	.....	.....	49.530	11.288	.....	.....	.....	25.152	.....	13.769	.....	.....	.....	.....	.....	.....	.....	+.261
23	2.814	34.30	....	.....	.....	8.80	3.40	.....	Protoxide of iron. 10.20	.....	30.24	.....	6.76	.....	.....	.....	2.66	.....	.....	3.64	+ 5.56
24	.....	31.00	....	.....	.....	18.00	.....	5.25	.....	.....	30.20	.....	.20	Sulphate of soda and muriate of lime, of magnesia, and of soda.	.....	.....	6.75	.....	.....	Water.	.....
25	.....	29.00	....	.....	.....	17.75	.....	6.00	.....	.....	35.00	.....	.50	.....	.....	.....	1.00	.....	3.00		+ 1.00
26	.....	29.77	....	.....	.....	12.00	.....	8.80	.....	.....	34.08	.....	1.52	.....	.....	.....	.....	.....	.....		+ .83
27	.....	31.00	....	.....	.....	24.00	.....	1.31	.....	.....	30.50	.....	1.04	.....	.....	.....	.....	.....	.....		+ 5.40
28	.....	22.75	....	.....	.....	9.375	.....	17.75	.....	.....	29.25	.....	.....	7.50	.....	.....	.....	.....	3.875		.....
29	.....	.....	7.0	1.0	.....	57.0	.....	5.0	.....	.....	2.6	.....	1.0	.....	.....	.....	.....	.....	9.6		+ .48
30	.....	.....	1.4	4.0	.....	44.5	.....	12.0	.....	.....	8.8	.....	4.7	.....	.....	.....	.....	.....	9.2		+ .4
31	.....	16.57	....	.....	.....	23.94	19.18	.....	.....	.....	40.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

REFERENCE.

No. 1, from Utica, La Salle county, Illinois.
No. 2, " Sandusky, Ohio.
No. 3, " Cumberland, Maryland.
No. 4, " Shepherdstown, Virginia.
No. 5, " Layer No. 9, from High Falls, Ulster county, New York.
No. 6, " do. No. 10, " " " "
No. 7, " do. No. 11, " " " "
No. 8, " do. No. 12, " " " "
No. 9, " do. No. 13, " " " "
No. 10, " do. No. 14, " " " "
No. 11, " do. No. 15, " " " "
No. 12, " do. No. 16, " " " "
No. 13, " do. No. 17, " " " "
No. 14, " Layer No. 3, from Lawrenceville, Ulster county, New York.
No. 15, " Akron, Erie county, New York.
No. 16, " Point-aux-Roches, Lake Champlain.
No. 17, " Layer No. 11, from Round Top Cement Works, near Hancock, Md.
No. 18. Vassy (France) cement.
No. 19. Theil (France) limestone (raw).
No. 20. Theil hydraulic lime, from the above.
No. 21, from Balcony Falls, Rockbridge county, Virginia (raw).
No. 22, " do. do. do. do. (burnt).
No. 23. Calderwood (Scotland) Roman cement (raw).
No. 24. Sheppy (England) No. 1 cement stone.
No. 25. do. do. No. 2 do.
No. 26. Southend (England) cement stone.
No. 27. Yorkshire do. do.
No. 28. Harwich do. do.
No. 29. Trass, } used by Gen. Treussart, at Strasburg.
No. 30. Pozzuolana, }
No. 31, from Lockport, Niagara county, New York (burnt, rather old).

227. The samples from Nos. 1 to 15, inclusive, were analyzed by Professor E. C. Boynton, Oxford University, Mississippi; Nos. 16 and 17 by Lieutenant Caleb Huse, Asst. Inst. Chem., etc., U. S. Mil. Academy; No. 23 by Professor F. Penny, Ph. D., F. C. S.; Nos. 29 and 30 by Berthier; the others were derived from reliable sources.

228. All the manufacturers of cement in the United States, pursue essentially the same process, in preparing the article for market. The only difference worthy of notice is, that while some use for burning the stone the ordinary perpetual kiln, of

a cylindrical form very nearly, terminating at the bottom in the inverted frustum of a right cone, in which the raw stone, broken into pieces of random size, but measuring not more than 8″ in the longest dimensions, and the fuel (either bituminous or anthracite coal) are mixed together in alternate layers, extending to the top of the kiln; others prefer the perpetual "furnace kiln," in which the heat is applied by means of furnaces, suitably arranged for wood or coal, near the bottom of the kiln, In some localities, as at Utica, Illinois, intermittent kilns. burning bituminous coal, are used.

Kilns used for burning cement stone.

229. For kilns of the first above-mentioned class, when anthracite coal is used, the latter should be broken up very fine. What is technically known as "second screenings," or "pea and dust," at the mines of the Delaware and Hudson Canal Company, and the Pennsylvania Coal Company, has been found to give the most satisfactory results in Ulster county, New York, among the Rosendale Works, and can be obtained at a trifling advance on the cost of transportation from the mines.

230. Whether *anthracite* or *bituminous* coal be used for burning, the quantity requisite and proper to be used will depend not only upon its kind and quality, but upon the character and composition of the cement stone, the form and locality of the kiln, and the skill of the burner. In the works situated on the Potomac River, at Shepherdstown, Hancock, and Cumberland respectively, the Cumberland semi-bituminous coal is used for burning; and, according to the opinion of Chas. H. Locher, Esq., proprietor of the James River Cement Works, at Balcony Falls, Virginia, is superior to the bituminous coal used by him, obtained near Richmond, Virginia. 3,500 lbs. of anthracite coal is sufficient to burn 100 barrels of cement, of 300 lbs. each.

Kind of fuel used.

Quantity of fuel necessary.

231. The ordinary perpetual kiln is set in operation by first filling it with thin, alternate layers of coal and raw stone, and

Starting the kiln.

then igniting it from below with light, dry wood. The layers of stone should not exceed six inches in thickness. The burnt stone is drawn out at the bottom, twice or thrice every twenty-four hours, raw stone and coal being

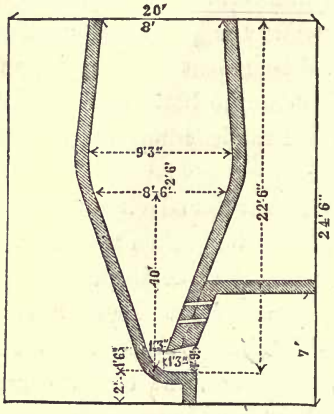


Fig. 11.

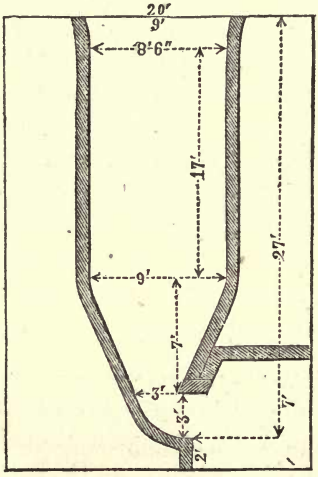


Fig. 12.

added in suitable proportions at the top after each drawing. Fig. 11 represents a vertical section, through the axis of the kiln and draw-pit, of the kilns used in Maryland and Virginia; and Fig. 12, of those preferred in New York and Ohio.

Ordinary perpetual kilns.

232. There are serious defects in the method of burning above indicated, for which no easy and practicable remedy has yet been devised, unless it be the furnace kiln or some modification of it. Some of the stone becomes so much overburnt, having reached the stage of incipient vitrification, as to be not only very variable in quality among the products of the several layers, and in many cases quite worthless, but exceedingly hard and tough, and consequently difficult to reduce to powder; while another portion,

Defects of method of burning.

Overburnt and underburnt stone.

usually the largest fragments, or those that have subsided too rapidly in the drawing, are underburnt and perhaps partially raw inside.* These also, being difficult to grind, should be selected out and subjected to a second calcination. Much of it, however, finds its way into the cement, and as the subcarbonates are known to be very prompt in hydraulic energy during the incipient induration, the injurious effect of the adulteration is not detected by ordinary tests.

Superior activity of the subcarbonates.

233. Lying between the two varieties of burnt stone just mentioned, one of which quite generally, and the other quite frequently, produces cement greatly inferior in quality to that which the stone, properly treated, is capable of yielding, we find another considerable portion, either too much or not enough burnt to develop the maximum energy and value of the cement, or in the general case, a mixture of both of these extremes, which offers no distinguishing physical feature by which it is possible to assort it from the rest. With *some* varieties of stone, these inferior products are yielded, by a heat of moderate intensity and duration, at a stage but little in advance of a condition of incomplete calcination; with *others*, they are produced as we approximate to a state of incipient vitrification; with *all*, they are essential elements in the individual properties of the stone, each quarry, and even the separate layers of the same quarry, possessing distinct characteristic features in this respect, which features are, withal, subject to considerable variations within very narrow lateral limits. The converse of these premises is also true, to wit, that the state of maximum energy corresponds to a condition of incomplete calcination in some cases; of complete calcination in others; while in others still, it is only produced by vitrification more or less complete. We

Other inferior products.

Stage of proper calcination varies with different stones.

* It will be seen hereafter, that some varieties of stone require to be overburnt to the stage of incipient vitrification, to develop their full value as cements.

Hence a constant examination of stones necessary.

therefore see the necessity for resorting to what appears to be the only efficient method of eliminating these elements of inferiority in hydraulic cement, viz: a constant daily examination of the stone by adequate tests, combined with a calcination in separate kilns of all those layers in a quarry which possess marked features of dissimilarity.

234. Suitably burnt cement may therefore contain a notable quantity of carbonic acid gas, and effervesce briskly with dilute hydrochloric acid, or it may not, according to inherent properties in the article itself. Each variety requires a special mode of treatment, as to the duration and intensity of the heat to which it should be subjected. This great difference is, perhaps, mainly due to the variable amounts of silica and the alkalies which the stone contains, but is by no means entirely dependent on them. Other ingredients exercise an important influence, particularly those which act as fluxes. The obscure reactions which take place at high temperatures, when a compound limestone is under treatment, cannot be accounted for by any general theory. It is fortunate that we are able, in a measure, to comprehend and estimate the results.

Each variety requires special treatment.

Probable cause thereof.

235. The great abuse to be abolished, is the mingling of dissimilar stones in burning. When this is done, most if not all minor evils will disappear. The idea that several kinds of cement stone—some of which require twenty, some thirty, and some forty hours, calcination—can be burnt together, in the same kiln, is both theoretically and practically absurd. Very little extra expense would be involved in a suitable separation and classification of the stone during the process of quarrying, and few of the manufacturers would require any more kilns than they usually keep going. The least extensive works keep from three to five in operation, with one or two in reserve, and there

Dissimilar stones should not be burned together.

are few quarries that would require a more extensive subdivision than these would accommodate.

236. Besides the several inferior products of the kiln just noticed, which are due to differences in the properties of the stone, there are others of a similar character, which have their origin in causes to a certain extent independent of these properties, and which, with proper precautions, are more or less under control: such as variations in the force of the draught through the kiln, due to changes either in the direction and force of the wind, or in the barometric state of the atmosphere; neglecting to draw the burnt stone with the requisite care, taking perhaps equal quantities at stated times, which may be either too much or not enough, depending on circumstances; not preserving the proper proportion between the fuel and raw stone, when adding these at the top, or not adding them at the proper time and in the suitable quantities; irregularities in the settling of the stone in the kiln at each drawing, which result in some portions being exposed to the heat a much longer time than others; the formation of "cinders," or vitrified pieces of stone, which adhere together or to the sides of the kiln, choking the draught, and retarding the expulsion of the carbonic acid gas: these, and many other variable causes, will always operate to such an extent as to render the proper calcination of the cement an operation of the utmost delicacy, and one requiring on the part of the manufacturer, a high order of intelligence, experience, and skill. Even supposing that all the stone yielded by a quarry and introduced into the cement is alike in composition and character, and requires the same treatment in burning, the theory upon which this practice of mixing the fuel and stone together in the kiln avowedly rests, is singularly at fault, and will by no means bear a critical examination; for, inasmuch as all the coal is consumed, or supposed to be consumed, during the calcination,—otherwise it is drawn in the cement and ground

Certain causes of bad burning within control.

Theory of mixing the stone and fuel not tenable.

up in it;—and as the proportion between the amount of fuel and raw stone, as well as the times of drawing the kilns and the quantities drawn are also pre-established; and as no provision is made to regulate the force of the draught, with a view to anticipate in a measure the intervention of one of the principal causes of variation referred to, it virtually assumes that a moderate heat, long continued, and a high heat, proportionally short in duration, will produce identical results, a premise which, with all its apparent plausibility, is directly opposed to the teachings of experience.

237. A perpetual "flame" or "furnace" kiln, for burning either lime or cement, patented by Mr. C. D. Page, of Rochester, N. Y., has recently been extensively introduced into the western part of the State of New York, which is intended to obviate some of the most glaring defects of all that class of kilns which require the fuel and stone to be mixed together. Either wood or coal may be used for fuel, although the details of the arrangements for supplying the heat are not exactly the same in each case. Figs. 13 to 18 represent sections of these kilns, whose horizontal section of the interior of the cupola is, it will be observed, of an oval or elongated form, with grates and flues ranged along either side. The conjugate axis of this oval, on a level with the fire, should not exceed five feet six inches. Its traverse axis may be increased to any length necessary to attain a given capacity, the coal-grates being correspondingly prolonged; and when the enlargement is considerable, suitable openings for drawing the burnt stone being made at the proper intervals along the sides. A little above the point where the flame plays directly upon the stone, small horizontal openings, Q, called "peak holes," are provided, which extend through the walls of the kiln into the cupola, and through which the progress of the burning may be ascertained from time to time, with a view to regulate the times of drawing the burnt stone, and the amount to be drawn. At the bottom of the kiln, and dividing the lower part of the cupola into two symmetrical

parts, a vertical division wall, O (Figs. 14, 15, and 16), is placed, which extends a little above the level of the furnaces, the object of which is to prevent a horizontal draught through the kiln. In burning common lime, this is sometimes omitted, or replaced by a wedge-shaped "air-saddle," through which a current of cold air constantly passes, which divides and gradually cools the lime as it falls below the fires, thereby rendering it less liable to injury from spontaneous slaking.

238. All who have used this kiln, whether for lime or cement, so far as any statements have been received from them, consider its success perfect, and speak of it in the highest terms. Mr. Lemuel Thompson, of Rochester, N. Y., who used one of them for burning lime, says: "My kiln is but 28 feet in height, yet I have been able to burn 320 bushels of perfect lime with 3½ cords of wood in twenty-four hours, and that, while the kiln was new, and of course, somewhat damp. The fires are applied at four points, producing a uniform heat on all points of the stone, and leaving not a stone unburnt. I find that I have burnt 44,000 bushels of perfect lime, with 394 cords of wood, being 114 feet of wood to 100 bushels of lime on the average, during which time I let the fire go down many times, owing to want of market for the lime, and by so doing, losing a large amount of heat. I never drew the kiln *down* the entire period of my running it."

239. One of them is in use for burning cement at Akron, Erie county, N. Y., by Messrs. Newman & Bro. Under date of March 12th, 1859, these gentlemen say: "We are now burning but 100 barrels, on account of the dulness of the market,—we can burn 130 barrels every twenty-four hours with three cords of wood. The peculiar shape of the cupola and furnaces are such, that the cement is perfectly and uniformly burnt, which adds 20 per cent. to the value of our cement over that obtained by the old mode of burning. Now, we know just what we can depend upon every day; we get no raw stone, no

cinders, nothing but pure cement. We can grind one-fourth more of this cement and with less power."

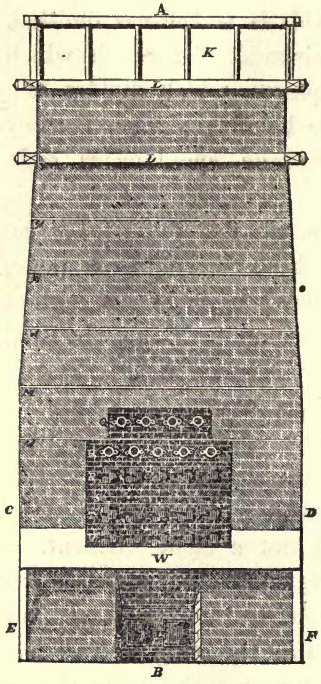


Fig. 13.

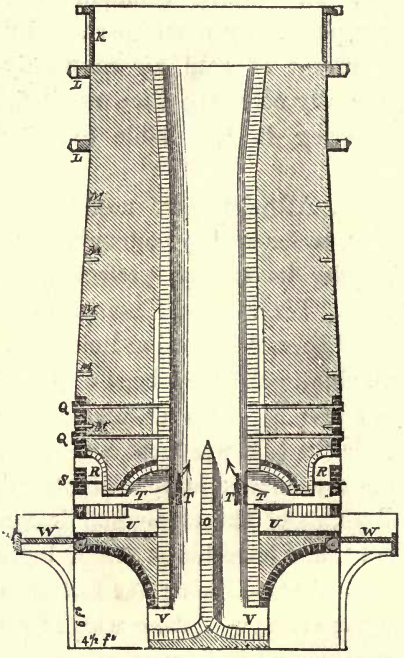


Fig. 14.

Fig. 13 shows a front elevation of the kiln with ten furnaces, designed for anthracite coal, although bituminous coal may be used in it, without any change being required. A section of the same, through A B, is represented in Fig. 14, and through C D, in Fig. 15. When wood is used for burning, the kiln is constructed, as represented in Fig. 16, with four furnaces, and in Figs. 17 and 18 with two furnaces. The parts marked K, show the crib at the top of the cupola; L and M, are timbers intended to bind the walls together; Q, are the peak holes, through which the progress of the burning can be watched; R, the feed ovens, for heating the coal, before it

passes through the dampers, S, into the furnaces, T; U, the ash-pits; V, the draw-pit; and W, a platform in front of the furnaces.

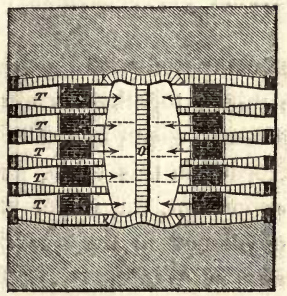


Fig. 15.

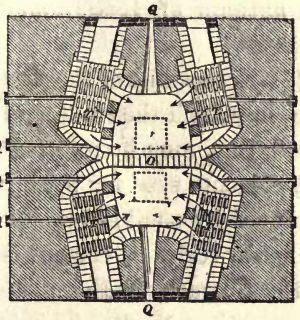


Fig. 16.

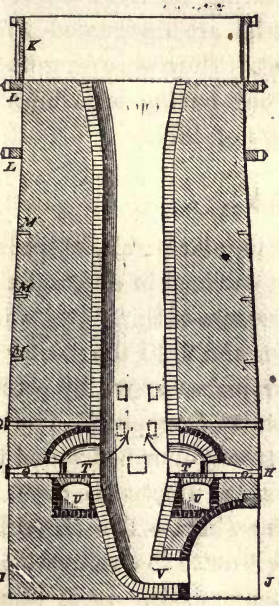


Fig. 17.

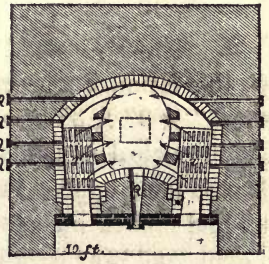


Fig. 18.

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240. In order to have the advantages claimed for this kiln fully tested, under circumstances that would lead to conclusive results, it was suggested to the Newark & Rosendale Company

to give it a thorough trial at their works in Ulster county, to which they readily consented. They adopted the coal-burning pattern (Figures 13, 14, and 15), which was erected during the autumn of 1859, under the personal supervision of the patentee.

241. The value of the *flame kiln*, as compared with the draw kiln, in which the stone and fuel are mixed together in alternate layers, may be inferred from the results given in Table V. The cements used for the mixtures recorded in this table, were produced by combining, in equal proportions, the upper and the lower series of cement layers as developed in the quarries of the Newark & Rosendale Company, at Whiteport, Ulster county, New York. This is the same combination which that company makes use of in manufacturing for the market. In Table V., the two cements under trial are designated *Flame Kiln* cement and *Draw Kiln* cement. They were samples of two lots made on the same day; one having been burnt in the new and the other in the old form of kiln.

242. TABLE V.

Shows the ultimate strength of rectangular parallelopipeds of mortar (2″ × 2″ × 8″), from cement calcined in different kilns, formed in vertical moulds, under a pressure of thirty-two pounds per square inch applied at the upper end until the mortar had "set," and broken on supports four inches apart by pressure from above, midway between the points of support. The mortars were kept in a damp place for twenty-four hours, and then immersed in salt water. Age of mortars, ninety-five days.

243. *Observations on the following Table.*—The *Draw* Kiln cement of the following table was not quite so quick-setting as the Newark & Rosendale cement usually is. It is possible that the mortars made from it are correspondingly inferior in strength and tenacity; although such a result would not, by any means, necessarily follow. Neither of the cements in Table V. comes up to the standard quality of the best Rosen-

TABLE V.

No. of the mortar.	Kind of cement.	Composition of the mortar.	Weight supported before breaking, in lbs.	Average breaking weight of each kind of mortar.
1	Flame kiln.	Pure cement (stiff paste.)	462	
2	" "	" "	510	
3	" "	" "	447	
4	" "	" "	529	
5	" "	" "	541	499½ *lbs.*
6	" "	" "	573	
7	" "	" "	470	
8	" "	" "	462	
9	Draw kiln.	" "	400	
10	" "	" "	400	
11	" "	" "	322	
12	" "	" "	314	
13	" "	" "	391	360¾ *lbs.*
14	" "	" "	369	
15	" "	" "	337	
16	" "	" "	353	
17	Flame kiln.	Dry cement vol. 1, Sand vol. 2, (stiff mortar.)	369	
18	" "	" " " " "	373	
19	" "	" " " " "	267	
20	" "	" " " " "	259	
21	" "	" " " " "	297	
22	" "	" " " " "	307	313$\frac{7}{11}$ *lbs.*
23	" "	" " " " "	314	
24	" "	" " " " "	353	
25	" "	" " " " "	341	
26	" "	" " " " "	279	
27	" "	" " " " "	291	
28	Draw kiln.	" " " " "	220	
29	" "	" " " " "	291	
30	" "	" " " " "	291	
31	" "	" " " " "	248	
32	" "	" " " " "	244	
33	" "	" " " " "	197	228$\frac{8}{11}$ *lbs.*
34	" "	" " " " "	197	
35	" "	" " " " "	202	
36	" "	" " " " "	204	
37	" "	" " " " "	209	
38	" "	" " " " "	213	

dale brands. They both range low in their breaking weights. As they were derived from one day's yield of quarry, and were manipulated and broken consecutively under the same conditions, the inference is, that sudden variations in the quality of the stone enter largely into the causes of this inferiority. In

fact, it is upon this hypothesis only that many striking discrepancies in the resistance of cements from the same quarry, treated precisely alike, and brought into market during the same month, can be explained. This illustrates the necessity of the precaution adopted and adhered to in all the trials reported in this work, of never assuming identity in quality of separate samples from the same manufactory, or even from different barrels of the same cargo, and of preserving within the range of each series of experiments, the means of an independent comparison of results.

The cement used for Table V., paragraph 242, and Table XXVII., paragraph 547, for example, came from the same quarry, were identical in the proportion adopted for combining the several strata, and were treated in precisely the same manner; yet in one the breaking weight of the cement paste, without sand, is only 499½ pounds for the flame kiln product, and 360¾ pounds for that of the draw kiln; while in the other (burnt in the draw kiln), it reaches as high as 1,002 pounds, and it is only when about 133 per cent. of lime paste is added, that the inferior limit of 360¾ pounds is approximately reached. This affords another proof of the necessity of keeping a close and constant watch upon the quarries and kilns, and of pursuing a rigid system of daily tests, to guard against deterioration in quality.

244. *Perpetual* kilns are always to be preferred to those that are *intermittent*, for burning either lime or cement, on account of the smaller quantity of fuel which they consume. As the object is chiefly to expel the water and carbonic acid, for which a bright red heat is sufficient, the most crude devices are sometimes resorted to, in order to accomplish this result. For making common lime, a rude pile of logs, burning in the open air, with the limestone thrown on the top, has frequently been made to answer. Cement, in case of necessity, might also be calcined in the same manner. As its manufacture, however, is seldom resorted to, except to supply a somewhat extensive demand of trade, and as its calcination requires considerable

skill, to produce an article of even medium quality, this primitive mode is seldom resorted to. Of all known methods of burning, it is the most expensive in the consumption of fuel.

245. For burning common lime, the simplest form of kiln in common use in Europe (and with some slight modifications, in the United States), is that represented in Fig. 19, in which wood

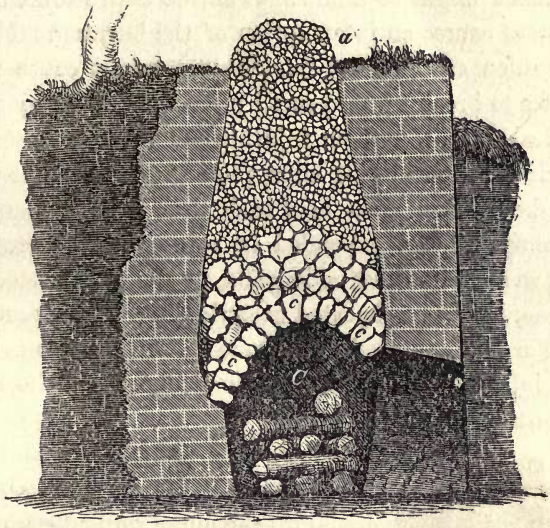


Fig. 19.

is used for fuel. This kiln is circular in horizontal section, and is generally constructed of rough-hammered limestone without mortar. It is usually located on the side of a hill, so that the top is accessible for charging the kiln, and the bottom for supplying the fuel, and drawing the burnt lime. The largest pieces of the stone to be burnt are first selected and formed into an arch, *c*, *c*, *c*. Above this arch, the kiln is filled by throwing the stone in loosely from the top, taking the largest first, and the smaller pieces afterwards. These latter are also piled up above the mouth of the kiln. The arched entrance, C, affords a convenience for supplying the fuel.

246. A necessary precaution in using intermittent kilns of

this class is, that the heat should be raised gradually to the required degree. There is a controlling reason for this: a sudden elevation of temperature will cause a sudden expansion of the stones, *c*, *c*, *c*, and the moisture will be driven off with such force as to rupture them in many cases. As these stones are of irregular shape and unconnected with mortar of any kind, the consequence might be a downfall of the entire contents of the kiln, and of course an interruption of the burning. Moreover, a too sudden elevation of temperature might cause many of the stones to break up into small pieces, and thereby seriously choke the draught, without injuring the arch.

247. In all intermittent kilns, there is an enormous waste of fuel, as the furnace must cool each time it is discharged, and the quantity of fuel expended in raising the contents of the kiln, as well as its thick side-walls, to the point necessary to burn lime, has to be repeated each time the kiln is recharged.

There are other defects: the stone nearest the fire is liable to become injured by overburning, before the top portions become fully caustic.

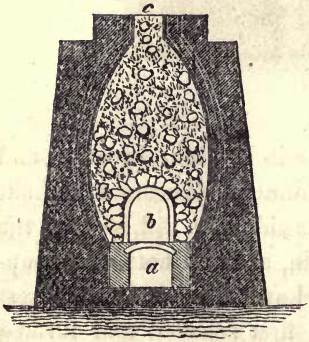


Fig. 20.

248. A better form of intermittent kiln is shown in Fig. 20. Besides the outer wall of stone masonry, there is an interior one of firebricks. The fireplace, *b*, rests on a permeated brick arch, through which there is a sufficiently free circulation of air, to secure the necessary draught.

249. *Perpetual* or *draw* kilns are intended to obviate the evils of irregular calcination, and useless expense of fuel, attendant on intermittent kilns. A very simple form of perpetual kiln, for burning lime with coal interstratified with the stone, is represented in Figs. 21, 22, and 23. It is much used on the continent of Europe. The interior is an inverted frustum of a cone, from

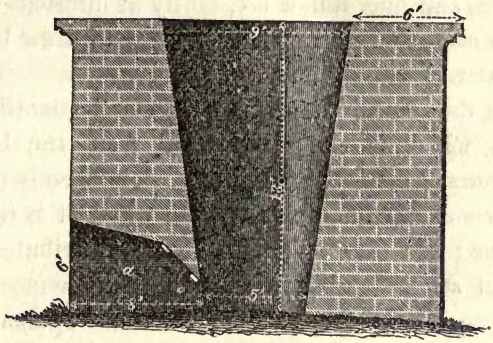


Fig. 21.

five, to five and a half feet in diameter at the bottom, and from nine to ten feet at top, and thirteen to fourteen feet high. It may be larger. This is generally surrounded by a thick, circular wall, from twenty to twenty-one feet in diameter, pierced at the bottom with three apertures for drawing the burnt lime.

Fig. 22.

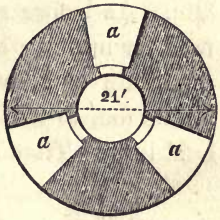


Fig. 23.

The draught may be regulated by doors placed at the entrance to the apertures.

A kiln of this form and of the dimensions indicated above, ought to yield about 500 cubic feet of quicklime every twenty-four hours, with a consumption of about two tons of coal. The quantity of coal, however, varies considerably with its kind and quality, and with the character of the stone to be burnt; some reaching as high as one-fourth of the weight of the limestone.

250. In all kilns of this description, when the stone and coal are mixed together, the burning is started by first placing a layer of light-wood at the bottom of the kiln, then a layer of coal on the wood, and then a layer of limestone. Layers of coal and limestone follow alternately, until the kiln is filled, and the stone is piled upon the top of the kiln. When the lime near the bottom is sufficiently burnt, the drawing of it

commences, and may follow constantly at intervals of half an hour. In some localities, it is customary to draw but three or four times every twenty-four hours.

251. In the consumption of coal, a small quantity of ash is produced, which is easily separated from the burnt lime. Wood is not so easily distributed as coal, uniformly through the kiln, on account of the difficulty with which it is reduced into small pieces; and even if it could be thus distributed, the large quantity of ash which it produces, taken in connection with a more or less considerable quantity of small fragments of stone, caused by the disintegrating influence of heat, would have a tendency to interfere seriously with the draught of air through the kiln. As before remarked (paragraph 237), Page's kilns are used for burning both cement and lime, in the western part of the State of New York. These kilns were introduced into Maine four or five years since, for burning Thomaston or Rockland lime. They have received various modifications in form

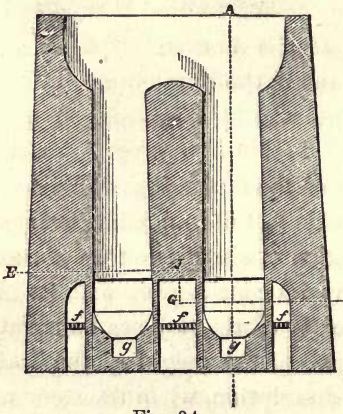


Fig. 24.

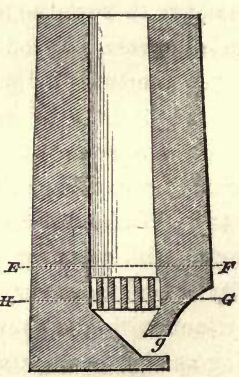


Fig. 25.

and detail since that time. Figures 24, 25, 26, and 27 represent a stack of two of the kilns now in general use in Rockland.

252. When lime-burning is conducted on a small scale in one kiln, two furnaces for the wood are introduced on opposite sides of the shaft, having their axes on the same diame-

ter. On a third side is placed the hole for drawing the burnt lime.

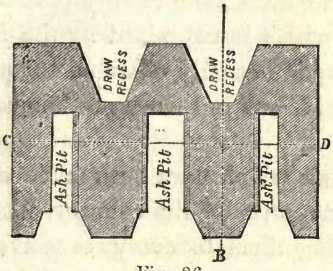


Fig. 26.

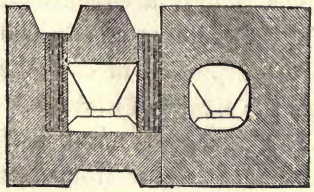


Fig. 27

253. In burning in any perpetual wood-burning kiln, it is essential that the draw-hole be kept tightly closed, except while drawing the burnt lime, and to regulate the draught entirely by the furnace doors.

254. Soft wood is used for lime-burning in Rockland, such as hemlock, pine, spruce, and fir. About four cords (of 128 cubic feet each) are required to burn one hundred barrels of lime, of 230 to 240 pounds each. This is a saving of about $\frac{3}{7}$ of the fuel, as compared with the consumption of intermittent kilns.

255. When first starting the kiln, the portion below the level of the grate, called the thimble, is filled with light-wood. The interior of the kiln, nearly up to the top, is also lined with wood one stick deep, set up on end. These precautions are necessary, first, because the stone on a level with, as well as below the grates, would otherwise be insufficiently burnt; and, second, because the expansion of the stone, when heated, would injure the kiln, if the latter was compactly filled.

The stone for burning is generally broken into pieces of various sizes, not exceeding ten inches cube.

256. A kiln holding enough stone to make 175 barrels of lime will yield, after being started, about 100 barrels every twenty-four hours. The stone is exposed to the heat from forty-two to forty-eight hours. The lime is drawn every six or

eight hours, and oftener, if the capacity of the thimble is rather restricted.

257. Moist limestone is said to burn more readily than that which is dry, a circumstance which is explained by the fact that the presence of aqueous vapor not only offers no obstacle to the evolution of carbonic acid, but in reality mechanically aids the escape of that gas.

258. The great number of trials which have been made with the cement stones from different parts of the country, within the last two years, by subjecting them to every conceivable degree of calcination, point so uniformly to the necessity of exercising the utmost care in conducting this delicate operation on a large scale, that it is impossible to gainsay its importance. They also establish beyond a doubt the magnitude of the error committed by manufacturers, in mingling the different varieties of stone together in burning. A few of the results will be briefly noticed, somewhat in detail.

Undoubted necessity of careful burning.

259. The stone from Rockbridge county, Virginia, from which the James River cement is manufactured, was broken into pieces of about $\frac{3}{4}$ of an inch cube, and calcined at a bright red heat, for periods varying from thirty-five minutes to eight hours. It required three hours to expel all the carbonic acid gas, below which point, all the samples gave a quick and energetic cement, which hardened readily under water, without being subsequently thrown down. The pieces burnt for thirty-five minutes and one hour respectively, were both partially raw inside. After three hours' burning, a rapid destruction of hydraulic energy ensued, which was in no degree restored when the heat was continued to eight hours. At this point, though not below it, some portions of the stone showed evidences of partial vitrification. For analysis of this stone, see Table IV. "The James River cement," as prepared for market, effervesces briskly with dilute hydrochloric acid, and will indurate under water at 65°

Stone from James River Cement Works.

F., in four to five minutes, and in six to eight minutes, so as to support the light and the heavy testing-wires, respectively.

260. At Point-aux-Roches, Lake Champlain, a good cement stone is found, which will sustain, without injury, a somewhat longer calcination than that from Virginia. It has never been used for cement, but when properly burnt, will compare favorably with our best cements, in hydraulic activity. From Point-aux-Roches.

261. Some of this stone was broken up and burnt as before, samples being removed from the fire at periods of 1, 2, 3, 4, 5, 6, and 7 hours, respectively. It required 6 hours to expel the last traces of carbonic acid gas. All the samples set readily both in the air and in water. That which had received seven hours' burning, however, even when allowed to harden in the air considerably longer than was necessary to support the heavy testing wire, would not bear immersion, but, after fifteen to twenty minutes, was reduced to the condition of soft paste. For analysis of this stone, see Table IV.

262. Two pieces of stone, from Lockport, N. Y., were sent for trial, the composition of both being almost identical. They are argillaceous limestones strictly speaking, and contain no magnesia. For their analysis, see Table IV.

The natural color of this stone is a grayish blue, the texture granular; the first specimen was fine grained, the second rather coarse. Both were subjected to calcination in a crucible, samples being removed for trial at the expiration of the first half hour of bright red heat, and subsequently at intervals of one hour, allowing nine hours to the last portions. From Lockport, N. Y.

263. Of the *first* specimen, all the burnings set rapidly in the air, but none of them perfectly sustained subsequent continued immersion in water, except the three corresponding to one-half hour's, two hours', and nine hours', calcination. The sample burnt eight hours did not fall entirely to pieces on immersion, but swelled slightly and was soon covered with sev-

eral deep cracks on the upper and lateral surface, in which condition it continued to indurate in a satisfactory manner, and underwent no further change. The trials with this stone developed some novel and exceptional properties. Among the several stages of calcination through which it passed successively, there were exhibited three points of maximum, and two of minimum, hydraulic energy. The two minima are found on either side of the sample burnt two hours, while the three maxima correspond with the samples burnt one-half hour, two hours, and nine hours, respectively. In mixing with water, a considerable elevation of temperature was exhibited by all the burnings. By working the paste over with the trowel as long as it remains warm, or by reworking it after it has commenced to swell and crack, it loses the objectionable and characteristic properties of the intermediate limes, and will retain its form in water; but is, at the same time, degraded in hydraulic power to a level with the eminently hydraulic limes. The portion burnt nine hours turned a dark bluish green color, a few hours after it had been immersed in water. This may be due to the carbonate of the protoxide of iron present in the raw stone, which parts with its carbonic acid gas after a long exposure to heat. The protoxide thus formed would turn green by the absorption of water, becoming the hydrated protoxide of iron ($FeO+HO$). The green color is readily driven off by heat. A more probable hypothesis appears to be, that it is the peroxide (Fe_2O_3), which is present in the raw stone. This, losing a portion of its oxygen at a high temperature, is converted by a new combination of its elements into the magnetic oxide (Fe_3O_4), a substance known, under certain conditions, to possess the properties of the pozzuolanas. This, however, does not account for the change in color.

264. The curves of the diagram, Fig. 28, will perhaps illustrate the peculiarities developed during the calcination more prominently than a written description can. Let *o* be the origin of co-ordinate, and the horizontal and vertical lines through

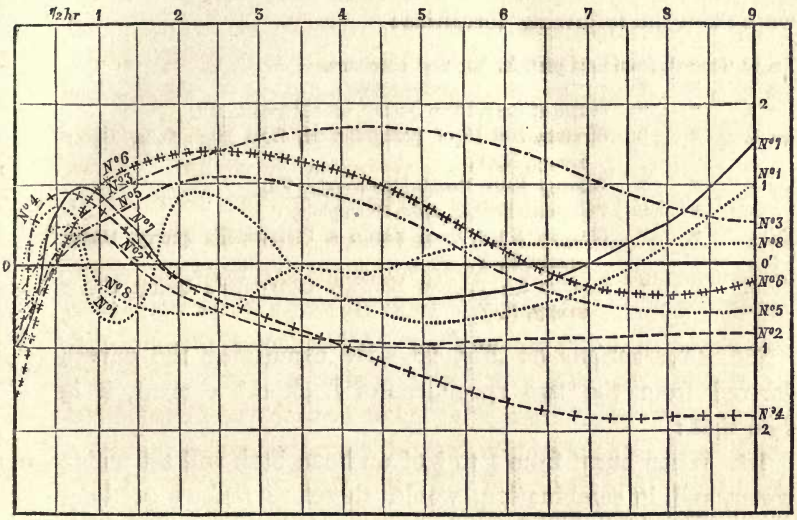


Fig. 28.

o the axes of abscissas and ordinates respectively. From *o* lay off on *o*, *o'* distances proportional to the several degrees of calcination, as determined by the duration of the heat. These distances are marked on the top horizontal line for every half hour, up to nine hours. On the perpendiculars, through the points thus determined, lay off distances from the line *o*, *o'*, that shall represent the hydraulic activity of the cements at the several stages of burning. These are positive ordinates, and lie above the line *o*, *o'*. The absence of hydraulic activity capable of sustaining immersion, or in other words, the relative rapidity with which the paste yields to the solvent action of water, is represented by negative ordinates below the line *o*, *o'*; the line *o*, *o'*, therefore, indicates the points of hydraulic equilibrium, so to speak, at which the cements either part with or resume the power of "setting" under water, if immersed in the state of paste. A curve traced through the several points obtained with a single cement, is called the *curve of energy* of that ce-

Curves of energy of certain American cements.

ment. The cements which furnished the curves of Fig. 28, were from the following localities:

No. 1. Cement, from Lockport, N. Y., first specimen.
No. 2. " " " second do.
No. 3. " " centre of Round Top Quarry, near Hancock, Md.
No. 4. " " Stratum No. 15 of paragraph 21, from High Falls, Ulster county, N. Y.
No. 5. " " Balcony Falls, Rockbridge county, Va.
No. 6. " " Point-aux-Roches, Lake Champlain.
No. 7. " " Stratum No. 7, from Martin & Clearwater's Quarry, Ulster county, N. Y.
No. 8. " " Stratum No. 3, from Martin & Clearwater's Quarry, Ulster county, N. Y.

265. *Observations on Fig.* 28.—By examining the curves derived from the two specimens of Lockport cement, it is seen that:

1st. When burnt from $\frac{1}{4}$ to $\frac{3}{4}$ of an hour, both will set under water, and, in combination, would therefore make a good cement when thus treated.

2d. Between $\frac{3}{4}$ of an hour and $1\frac{1}{2}$ hours' calcination, the first will not set under water, while the second will; and the properties of the combination would depend on the proportion adopted.

Observations on diagram, Fig. 28.

3d. Two hours' burning exactly reverses this state of things, the first setting under water, while the second will not, and this condition obtains until the calcination is continued for $3\frac{1}{2}$ hours.

4th. Beyond this point, neither will set under water, until a calcination of $7\frac{1}{2}$ hours is reached, when the first resumes its hydraulic action, and continues so, the second remaining as before.

As there is no greater diversity among the eight varieties of cement represented in diagram, Fig. 28, than is ordinarily to be found in the several layers of the same quarry, which, according to the usual custom, are burnt together, we can to some extent realize, by an inspection of the diagram, the practical effect of the system now in vogue among manufacturers.

5th. All the eight varieties, burnt from ½ to ¾ of an hour, set under water, and when thus treated, would make a quick setting combination. This corresponds with the well-known fact that the subcarbonates are very actively hydraulic.

6th. Calcined two hours, four of them set well under water, and four do not.

7th. Burnt four and a half hours, three of them set under water, and five do not.

8th. Burnt six and a half hours, only two of them set under water, (and one of these two rather sluggishly), while six do not. Of these latter, however, No. 4 and No. 2 may be regarded as intermediate limes; while No. 7 and No. 1 are intermediate limes at some stages of calcination, and ordinary hydraulic limes, apparently, at others. For remarks on the stone which furnished curve No. 4, see paragraph 21, where it describes layers nine to sixteen inclusive, of the deposit in Ulster Co., N. Y.

9th. Burnt eight hours, the specimens are again equally divided, that is, four of them will bear immersion in water, and four will not.

10th. It is evident that the quickest setting combination of the eight varieties of stone, would be secured by burning them separately, to that degree indicated by the highest point in their respective curves; while the combination least likely to sustain immersion, would in like manner correspond with the lowest points in the curves.

11th. Inasmuch as the quickest setting cements do not always give the strongest mortars, while slow setting ones may excel in that respect, it may be inferred that curves which would represent the degrees of calcination corresponding to the several degrees of *strength* of cement gangs, varying with and dependent on the calcination, might differ very materially from those given in the diagram, which have especial reference simply to the hydraulic *activity* of the gangs, when immersed in the state of paste. Such *curves of strength* could readily be

constructed, however, by making mortar prisms of the products obtained at the several stages of calcination, and subjecting them to the usual breaking test. Such a diagram, comprehending all the dissimilar layers of a cement deposit, and corrected from time to time, as often as the changeable character of the rock might require, would furnish the only unerring guide to a proper calcination of the stone of the quarry.

12th. As all the specimens subjected to nine hours' burning had parted with the whole of their carbonic acid, while some of them reached the same condition in a much shorter space of time, it follows that M. Petot's deduction, that cement stone "at the point of complete calcination" gives "a substance nearly inert," is by no means correct as a principle, but is only an improper generalization of results obtained in a particular case; for the diagram shows that at every stage of the burning, some of the curves lie above the zero line, and therefore represent more or less energetic cements. It is true that at six and a half hours' calcination, six curves out of the eight lie below that line, and might therefore, relatively speaking, be said to represent "inert substances;" but with this exception, every stage of burning gives active cements from about one-half of the specimens under trial, while one specimen from the Round Top quarry (curve No. 3) was quick and energetic at every stage, after the first twenty minutes.

266. We cannot do better perhaps in this connection, than to give a diagram of the *curves of energy* of several calcareous substances, as constructed by M. Petot. We know from the foregoing discussion that the one representing, or said to represent, hydraulic cement (plastic cement, as it is therein termed), must refer to a particular case only. It is possible that the others do also. M. Petot does not inform us on this point, and our experiments have not extended far enough to enable us to speak with confidence on the subject. The curves are indicated in the diagram, Figure 29.

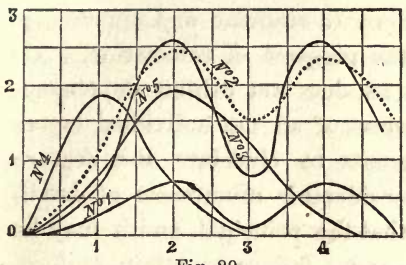


Fig. 29.

The numbers on the lower horizontal line (marked zero line), represent the distances from the *o* point, proportional to some of the principal degrees of torrefaction.

No. 1 corresponds to the degree of moderate burning of bricks.
No. 2 " " " thorough " " "
No. 3 " " " complete calcination of fat lime.
No. 4 " " " super-calcination of fat lime.

On the perpendiculars through these points, distances are laid off, above the zero line proportional to the hydraulic energy of each particular product, at the several stages of calcination respectively. The curves of energy are the lines drawn through the points thus determined. A total want of hydraulic energy is indicated when the curve lies on the zero line.

Curve No. 1 belongs to fat lime.
" " 2 " " hydraulic lime.
" " 3 " " " (or plastic) cement.
" " 4 " " calcareous clays suitable for pozzuolana.
" " 5 " " clays not calcareous.

267. In the absence of any information as to the method pursued in obtaining these curves, and knowing from our trials that curve No. 3, said to represent cement stone as a class, does not so represent it, and, in all probability, was obtained from a single sample, it seems safe to infer, that M. Petot restricted his investigations of the other substance to individual specimens also. With the exception of fat lime, it is believed that all the substances which he tried, represented in Figure 29, might be expected to produce curves, as dissimilar in character as those obtained for American cements.

268. It would appear, from the results given above, that the hydraulicity of cements derived from the same quarry and bearing almost identically

Capricious variations during calcination.

the same composition, is subject to singular and apparently capricious variations during the progress of calcination. Although the diagram, Figure 28, does not exhibit the characteristic peculiarities in this respect of all the individual layers of any one quarry, experiments to elucidate this feature have been carried on with considerable minuteness of detail, and show quite conclusively that the principal, and it may be said, the only cause of the frequent failure to attain uniform results by any known method of calcination, lies in the obscure, because unstudied changes in hydraulic character, through which the stone successively passes during the burning. There are, it is true, many layers of stone that yield a really good and energetic cement at any and all stages of calcination between the points of half calcination and complete vitrification; and it luckily so happens, so far as recent observation teaches, that this kind of stone is very extensively distributed throughout the country, and comprises at least one-half of the thickness of the deposits to which we now look for our supply, viz.: those in Ulster county, New York, and on the Potomac and James Rivers in Maryland and Virginia. The negative character of some of the other contiguous layers of these deposits, as well as the positively injurious character of many, or rather, the indifferently good as well as the really bad cement obtained by an injudicious calcination of them, is thereby partially redeemed, or, in a measure, counteracted, as it is the average aggregate result we obtain in all cases in practice.

Some cements are good at all stages of calcination.

They redeem the defects in others.

269. Not unfrequently, as before remarked, the changeable cements, as they may be termed, when burnt to a certain point, possess in a marked degree all the objectionable properties of the intermediate limes,—setting rapidly when first mixed into a paste, and immersed in water, but possessing no permanence or stability; while sometimes above and sometimes below this point, and

Cements act like intermediate limes at certain stages of burning.

Maximum and minimum hydraulicity.

often both above and below it, a good cement is produced. At other times this condition of things is reversed, there being but one point of maximum, while there are two of minimum hydraulicity. Sometimes the substance conducts itself like imperfectly slaked common lime, and begins to swell up and soften the moment it is immersed, possessing not even the dangerous energy of the intermediate type; at others again, it appears to be almost entirely inert, like clay. The influence which these changes exert on the strength and hardness of the resulting cement, presents a subject for serious inquiry. That those varieties which, at any stage of calcination, give intermediate limes, should be either burnt by themselves, and with extra care, or else carefully excluded from the combination, there would appear to be no doubt; unless, indeed, the precaution is taken to manufacture and store them in bulk, several months before they are used. This is believed to be a specific remedy for the defects which belong to this type of cements. It, however, degrades them in hydraulic energy, as well as in strength and hardness, to a level with ordinary hydraulic limes. No adequate trials of strength have been made with any of those varieties which, at any stage of calcination below that of incipient vitrification, part entirely with the power of sustaining immersion in water.

These changes call for serious inquiry.

Cements that can produce intermediate limes to be burnt by themselves, or kept some time before use.

Objections to the last-mentioned precaution.

270. The results given in Table VI. were obtained with Layer No. 12 of the deposit at High Falls, Ulster county. The table contains four kinds of cements designated severally, Number One, Number Two, Number Three, Number Four. They were obtained by burning the stone in a small kiln, about seven feet deep and twenty inches to twenty-four inches in diameter, called a "try" kiln, and subsequently separating the burnt stone into four portions, differing from each other in the

Trials with Layer No. 12, Ulster Co. deposit.

degree of calcination which they had respectively attained. These after being ground, were passed through wire sieve No. 80, in order to secure a uniform degree of pulverization.

271. *Number One* was underburnt stone; the fragments, when broken open, showed a raw core, in the centre, of the natural color of the stone, though, on the exterior, they presented the appearance of having been sufficiently calcined.

First stage of calcination.

In the ordinary process of manufacturing cement, nearly all this variety is used. The only precaution usually observed is to exclude those portions that might, on account of their hardness, endanger the safety of the machinery in grinding. In assorting the burnt stone, it is readily distinguished by its greater specific gravity.

272. *Number Two* was selected by an experienced burner, as the inferior limit of complete calcination. None of the fragments contained a raw core, and none showed any vitrification on the exterior. They effervesced with dilute hydrochloric acid very slightly.

Second stage of calcination.

273. *Number Three* was well burnt, and was selected to represent the superior limit of complete calcination. All the carbonic acid gas was expelled, but no vitrification had taken place.

Third stage of calcination.

274. *Number Four* was *overburnt* and *vitrified* stone, commonly called "cinders" by the workmen. A small proportion only of this variety finds its way into the cement manufactured for market. From its extreme hardness, a due regard to wear and tear of machinery suggests its careful exclusion. It usually occurs in masses that are glazed over and run together, and it is easily distinguished from the other portions of the kiln.

Fourth stage of calcination.

275. TABLE VI.

Showing the effect of different degrees of calcination, on the quality of hydraulic cement. The mortars were

in the form of rectangular parallelopipeds, $2'' \times 2'' \times 8''$, which had set, under a pressure of 32 lbs. per square inch. They were allowed to harden one day in the air, and were then kept in sea-water. They were broken on supports four inches apart by a force applied at the middle. In all cases, the composition of the mortar was cement powder 1 vol., sand 2 vols.; age of mortars, 95 days.

No. of the mortar.	Kind of cement. It was all derived from Layer Number Twelve, Ulster County, N. Y.	Weight supported before breaking, in lbs.	Average breaking weight of each kind of mortar, in lbs.
1	Number One, underburnt	216	
2	" " "	204	
3	" " "	189	
4	" " "	181	
5	" " "	300	226.
6	" " "	246	
7	" " "	248	
8	" " "	263	
9	" " "	204	
10	" " "	209	
11	Number Two, inferior limit of complete calcination	203	
12	" " " "	209	
13	" " " "	209	
14	" " " "	213	
15	" " " "	197	245.
16	" " " "	275	
17	" " " "	281	
18	" " " "	298	
19	" " " "	326	
20	Number Three, superior limit of complete calcination	348	
21	" " " "	353	
22	" " " "	263	
23	" " " "	259	276.
24	" " " "	267	
25	" " " "	211	
26	" " " "	259	
27	" " " "	255	
28	Number Four, vitrified	82	
29	" " "	88	
30	" " "	79	
31	" " "	73	82.
32	" " "	83	
33	" " "	86	
34	" " "	79	
35	" " "	76	

Observations on Table VI.—The cements were fresh from the kiln. Number One possessed the greatest degree of hydraulic activity, and required but ten or twelve minutes to set under water, so as to support the light testing wire. Number Two required twenty-five minutes; Number Three, thirty to thirty-five minutes; and Number Four, ninety to one hundred minutes, to attain the same degree of induration. Similar results, as regards simply the superior promptness of the initial energy of underburnt cements, were obtained with other strata from the same locality, as well as with stone from the Potomac and James Rivers. Each cement has, however, beyond the stage of incomplete calcination, its marked peculiarities of strength and hydraulic activity.

276. This property is so universal, that even common fat lime may be rendered moderately hydraulic, and the initial energy of hydraulic limes considerably increased, by suitable underburning. This increased activity, however, does not appear to be accompanied by a corresponding augmentation of the strength of the resulting paste, especially in the genuine cements, as seen by Table VI.

Hydraulic activity of underburnt limes very general.

277. After the mortars of the foregoing table were mixed, the balance of the four varieties of cement was carefully preserved in a dry room for subsequent trial. At the end of six months, other prisms were made of the cement paste without sand. The results are given in the following table:

TABLE VII.

Showing the breaking weight of rectangular parallelopipeds ($2'' \times 2'' \times 8''$) of pure cement mixed stiff, of different degrees of calcination, broken on supports four inches apart by a pressure at the middle. The mortars "set" under a pressure of thirty-two pounds per square inch, and were put in sea-water when one day old, and kept there until broken, at the age of

ninety-five days. The cement was measured by volume of powder.

No. of mortar.	Kind of cement.	Penetration of point in inches.		Weight supported before breaking.	Average breaking weight of each kind of mortar.
		1 impact.	2 impacts.		
1	Number One, underburnt	.097	.170	691 lbs.	654 lbs
2	" " "	.107	.187	615 "	
3	" " "	.105	.187	689 "	
4	" " "	.195	.182	621 "	
5	Number Two, inferior limit of complete calcination	.075	.127	542 "	603 "
6	" " " "	.050	.100	519 "	
7	" " " "	.050	.100	689 "	
8	" " " "	.060	.112	662 "	
9	Number Three, superior limit of complete calcination.	.130	.230	546 "	494 "
10	" " " "	.100	.170	443 "	
11	Number Four, vitrified	.150	.260	863 "	817 "
12	" " "	.106	.170	595 "	
13	" " "	.090	.150	918 "	
14	" " "	.090	.165	894 "	

The results given in Table VII. were so different from those obtained for Table VI., in the character assumed by the vitrified cement, that other trials were made with the same kind of stone in order that all doubts, as to the relative value of the products, derived at the several stages of calcination, might, if possible be removed. The same sized parallelopipeds ($2'' \times 2'' \times 8''$) were made without pressure (some with and some without sand). These were put in sea-water when one day old, and kept there, until broken at the age of *sixty* days, the supports, as usual, being four inches apart. Several trials gave the following average results. The cement was measured by volume of dry powder.

TABLE VIII.

No. of cement.	Degree of calcination.	Breaking weight of prisms of	
		Cement without sand.	Cement, 1. Sand, 2.
1	Number One, underburnt	557 lbs	190 lbs.
2	Number Two, inferior limit of complete calcination	646 "	224 "
3	Number Three, superior limit of complete calcination	513 "	143 "
4	Number Four, vitrified	670 "	237 "

278. *Observations on Tables VI., VII., and VIII.*—The dis-

crepancies between the breaking weights of Number Four (vitrified cement) in the three Tables, appear irreconcilable on any other supposition than that of error in recording the results of Table VI. It is possible that cements Number Three and Number Four, may have been exchanged accidentally while making the mortars of Table VI. By making this transposition in Table VI., that is, by exchanging the names of cements Number Three and Number Four; the results of the last three tables are more readily comprehended, cement Number Four giving the strongest of the four mortars in each case, and cement Number Three, the weakest.

279. We will now, as a matter of interest, construct, in the manner indicated in the 11th observation on Fig. 28, the *curve of strength* of the cement used for Tables VI., VII., and VIII., based on the several progressive stages of calcination, as described in paragraph 266, and the breaking weights given in the three tables.

Curve of strength.

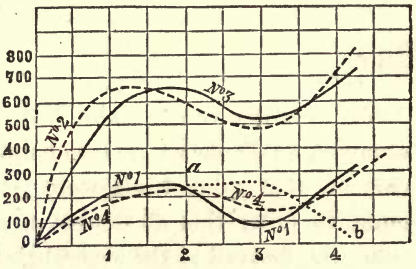


Fig. 30.

280. These breaking-weights were obtained under four varying conditions, as regards age and kind of mortar, and the curve of strength for each is given in Fig. 30.

281. These conditions (see Tables VI., VII., and VIII.,) are:

1st. Cement vol. 1, sand vol. 2	Age 95 days, gives curve No. 1.
2d. Pure cement . .	Age 95 days, gives curve No. 2.
3d. Pure cement . . .	Age 60 days, gives curve No. 3.
4th. Cement vol. 1, sand vol. 2	Age 60 days, gives curve No. 4.

282. The abscissas are laid off on the horizontal line from the zero point to the numbers 1, 2, 3, and 4, in lengths corresponding to the four degrees of burning (paragraph 266). On the ordinates through the points

Explanation of Figure 30.

1, 2, 3, and 4, distances proportional to the strength of the prisms, at the rate of 100 lbs. to $\frac{1}{8}$ of an inch, are laid off. The points thus obtained, fix the position of the curve.

283. The dotted branch *a b*, of curve No. 1, corresponds to results given in Table VI., on the supposition that they are there recorded correctly, while the full branch supposes the existence of the error already referred to above, to wit, that the average breaking weights of mortars from cement Number Four, Table VI., is 276 lbs., and from cement Number Three, 82 lbs. and not as recorded.

284. The fact that curves Nos. 2, 3, and 4 give two points of maximum strength, while curve No. 1 does not, except under the supposition of error, affords a geometrical confirmation of this hypothesis.

285. We have not constructed the *curve of strength* of any of the American cements, except that made from layer No. 12 of the Ulster Co., N. Y., deposit, recorded in the last three tables, and illustrated by Fig. 30.

286. We see that a proper treatment of this stone requires that the calcination should stop at or below the inferior limit of complete calcination, or be carried to the point of vitrification, and that, at the point of superior limit of complete calcination, and just before vitrification sets in, the mortars are deficient in strength. The impropriety of mixing this stone, for burning, with another differing from it in the period or periods of time necessary to reach the maximum points of the curve of strength; or, of burning many kinds of stone together, whereby several maxima and minima of strength may be developed simultaneously, needs no comment.

Care to be exercised in burning.

287. If the layers of cement rock preserved individually a uniform character over extensive areas, it would be a simple matter to test them all in the manner above described, construct their respective curves of strength, and establish for the manufacturers the necessary rules and precautions for burning;

but the changeable character of the deposits renders such a labor necessarily one of constant recurrence, and one of the appropriate duties of the manufacturer himself. We have not therefore undertaken this work, except so far as seemed necessary to illustrate the subject.

288. The cement stone, after calcination, is reduced to powder between ordinary millstones, after being first passed through a "cracker," which crushes it up into pieces not exceeding the size of a pea or a hazel-nut. The cracker is made of cast iron (Figs. 31 and 32), and consists essentially of a frustrum of a solid cone called the core, working concentrically within the inverted frustrum of a right hollow cone, both being provided on their adjacent surface with suitable grooves and flanges for breaking up the stone as it passes down between them. The elements of the lower portions of both cones make a smaller angle with the common axis than those pertaining to the upper portions, with a view to lessen the strain, and the effects of sudden shocks upon the machinery, by securing a more gradual reduction of the stone to the required size. These lower portions being subject to very rapid wearing, are made of chilled iron, and are moreover cast in separate pieces, in order that they may be replaced by new ones, as occasion requires. The greatest diameter of the core at the top, including the flanges, is 9 inches, at the bottom 5½ to 6 inches, and its height is 15 to 16 inches. The diameter of the shell, measured within the largest flanges, is 14 to 15 inches at the top, and 5½ to 6 inches at the bottom, a trifle greater than that of the core; its height is 16½ to 18 inches. One cracker of this size, working with a velocity of 80 to 85 revolutions per minute, is sufficient for a mill grinding 250 to 300 barrels per day. It is customary to provide one cracker for every two run of stone. For the cement mills, the French Burr stone is generally used in

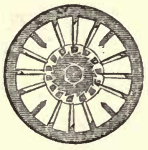


Fig. 31.

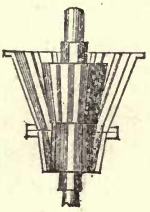


Fig. 32.

this country, except in Ulster county, New York, where the Shawangunk conglomerate or grit (Formation IV. of Professor Rogers' classification of the Rocks of Pennsylvania and Virginia) has been found to be an excellent substitute. In the vicinity of High Falls, it occurs only a few feet below the cement deposit, and in Rochester township, a few miles further west, is extensively quarried for millstones. These are of various sizes, from 2½ to 5 feet in diameter. When driven with full power, one run of the largest size will grind, on an average, 300 pounds of cement (one barrel) in four minutes, as ordinarily prepared for market, or in six minutes, if ground extra fine, as it should be. To carry the degree of pulverization beyond a certain point involves a consumption of either power or time which appears to be strikingly out of proportion to the results secured thereby. For example, a cement of which 85 per cent. will pass a fine wire sieve of 6,400 meshes to the superficial inch (No. 80), cannot be ground so that 95 per cent. will pass the same sieve without doubling one or the other of these functions. This accounts for the fact that the cements sent to market are, as a general thing, imperfectly ground. The capacity of a cement to receive sand, other things being equal, varies directly with its degree of fineness, which is, therefore, for this reason, an important consideration to consumers to say nothing of other advantages secured by approximating to an impalpable powder. Not more than 8 per cent. of a cement should be rejected by a sieve of 6,400 meshes to the square inch.

Cement apt to be ground too coarse.

289. In practice, one solid cubic yard of raw stone is found to yield an average of 2,700 lbs. or nine barrels of cement, exclusive of those portions rejected in assorting the burnt stone.

290. The Rosendale cements are packed in barrels from the mill-spout as fast as ground. In Virginia, the custom prevails of storing the ground element in bulk, until sent to market, a practice which, besides involving additional expense, injures the hydraulic quickness and energy of all cements, except

those containing too much free lime, or which border on the intermediate limes. The objectionable properties, in such cases, disappear in time, but invariably at the expense of the hydraulicity. It must be admitted that there are very few quarries in this country, that do not assume such a character at times, that the cements are of better quality, and may be more safely used by ordinary mechanics when six months old, than when freshly ground.

Bolting cement.

291. Attempts have been made to economize the power necessary to produce a very high degree of pulverization, by passing the ground cement through fine wire bolts. It was found, however, that these bolts required such frequent renewal, as to render their use in every way inexpedient.

Color of cement.

292. The color of the manufactured cement being due principally to the presence of a small quantity of oxide of iron, and sometimes of manganese, or to the carbonates of these oxides, which, for all practical purposes, are conceded to be a passive ingredient in hydraulic mortar, should be a matter of indifference to consumers, except in special cases, as in exterior stucco work or ornamentation, in pavements, and in the fronts of edifices, when a particular shade of color is sought for. In fact, the presence of a large proportion of the coloring principle, like that of any other inert substance, might be expected to have a tendency to deteriorate the quality of the mortar, by diminishing the cohesive strength of the cementing substance, and, therefore, if taken into consideration at all, ought, at least, to direct suspicion to the darker varieties. On the contrary, there exists among dealers generally, a strong prejudice in their favor, which, if analyzed and traced to its source, will be found to have had its origin, not in opinions based upon experiment, or even upon a theoretical examination of the substances, but in the pernicious system of building by contract, so extensively, and it might almost be said, so exclusively practised in this country,

and under which nine-tenths, and perhaps nineteen-twentieths of our masonry work, is superintended by men whose utmost endeavors are directed to "economy of construction." They, therefore, encourage and cater to a popular belief of their own creation, that a dark colored mortar is necessarily a rich and energetic one, and give the preference to those cements which will sustain a large dose of sand, without presenting the appearance of having been injuriously diluted with it. The fact that some of the cements first discovered and manufactured in this country on the line of the Erie Canal, and in Connecticut Valley, which were little more than eminently hydraulic limes, were light in color, while the excellent Parker's Roman cement, which appeared here soon after, was very dark-colored, renders it more difficult to abate this prejudice. No importance whatever is accorded to the fact, that the *quickest setting* cements manufactured at the present day happen to be light-colored, and that the Portland cements, both natural and artificial, though rather slow-setting, have never been surpassed in strength and hardness by any of the natural cements of this country or Europe.

293. As to the oxide of manganese, the idea, at first promulgated by the chemist, Bergmann, and subsequently endorsed by Guyton de Morveau, that the hydraulic property was due to the presence of a few hundredths of that substance, has long since been abandoned, for the obvious reason that some of the best cements known are entirely devoid of it.

Oxide of manganese.

294. The extent to which the oxide of iron exerts its influence, if at all, upon the induration of hydraulic mortars, is still a subject of controversy, as well as the question whether the virtues claimed for it by some writers, rest with the uncombined peroxide or protoxide, or with a carbonate of one of these bases. The fact, however, appears to be well established that their presence does not confer hydraulic activity, whatever may be their action at some

Oxide of iron.

subsequent stage of the induration. We also know that, although some of the best cements known, as, for instance, the cement of Vassy, in France, and Parker's Roman cement, contain a comparatively large amount of the carbonate of the protoxide of this metal, the former .11$\frac{6}{10}$, and the latter .06, there are many good cements in the United States which contain less than .02, while there are some meagre, non-hydraulic limes, which contain, after calcination, as much as .10 of the protoxide. It has been suggested by Messrs. Malaguti & Durocher, in a paper submitted to the Academy of Sciences in July, 1854, that the presence of the peroxide in hydraulic mortars exposed to the action of sea-water was beneficial. The following conclusions to which their experiments led them are very general, and were to be considered at the time as simply initiatory to a more extensive examination.

1st. Those cements which are reported as the best for "resisting the destructive action of sea-water, always contain a notable quantity of peroxide of iron."

2d. Certain combinations of silica, alumina, and lime "give, under otherwise similar conditions, very different reactions, according as they are deficient in, or contain large quantities of oxide of iron."

295. M. Vicat throws the weight of his high authority against the inference to be drawn from these two propositions, and arrays a number of "well ascertained facts in direct opposition to that method of explaining the resistance to the effects of sea-water," in the form of tabular statements, exhibiting the amount of peroxide of iron in several hydraulic limes, cements, &c., possessing in different degrees the power of withstanding these destructive influences. He also in effect reaffirms the opinion expressed by him as early as 1846, and subsequently in 1860, that peroxide of iron exerts an *injurious* influence upon hydraulic materials. He shows that of two cements, both *indestructible* by sea-water, one (Medina) contains .12, and the other

Oxide of iron.

(Cahors) .055 of the peroxide of iron. Of cements slightly destructible, the Pouilly contains .051; the Vassy, .0735; and the Portland, .053. Of cements entirely destructible in a few days' immersion, that from Gutaéry (Lower Pyrénées) contains .059. Among the natural pozzuolanas, some from Rome, that stand the action of sea-water well, contain .12 of this peroxide; others from Naples, that are unsatisfactory under similar circumstances, contain .163; those from the Isle of Bourbon, still worse, contain .35; while all the pozzuolanas from the volcanoes of the Vivarais, which are worthless, contain, on an average, .20.

296. M. Vicat further states that all artificial pozzuolanas prepared with white clay, and carefully applied, resist the action of sea-water.* Some of them do not contain any iron at all, and most of them not more than .012 to .02, while the celebrated lime of Theil, hitherto regarded as the only one known that could, with sand alone, furnish a mortar indestructible by sea-water, contains but a trifling quantity of peroxide of iron, and sometimes none at all, while some other limes, most successful in fresh water, and containing as much as .9 or .10 of peroxide of iron, are destroyed in salt water after a few days. The conclusion drawn by M. Vicat is that "it is difficult to attribute a useful influence to the peroxide of iron," in virtue of the trials made by MM. Malaguti & Durocher. It is submitted that some doubts may, with reason, be entertained with regard to the correctness of the premises assumed by M. Vicat, viz., that if this oxide exercises the influence suggested by those gentlemen, in augmenting the power of hydraulic mortars to withstand the dissolving action of sea-water, the extent of this influence should be invariably in pro-

The correctness of M. Vicat's opinion the subject of doubt.

* In view of the suspicions that have recently arisen in reference to the stability of maritime structures laid up in artificial hydraulic mortars, entertained by some of the ablest European engineers, and men of high attainments in practical science, we must be allowed to express some doubts as to the correctness of this premise.

portion to the quantity of the oxide present. May not the molecular state of the oxide, and the obscure and variable modifications and reactions which it, like some of the other constituent elements of hydraulic mortars, may undergo during the calcination,—conditions which are known to vary materially with the duration of the calcination, and the degree of heat under which it is effected,—have an important bearing upon this question? May not a portion of this oxide exist in a condition favorable to its entering into stable and indestructible combinations, while another portion is practically inert or even injurious in its tendency, as is not unfrequently, and perhaps generally the case, with the silica and the lime? Finally, may not the iron be present in several forms, such as the protoxide FeO, the peroxide Fe_2O_3, the magnetic oxide Fe_3O_4 or perhaps $(FeO + Fe_2O_3)$? This last compound, in the form of cinders or scales thrown off under the smith's hammer, has long been known to possess the property of pozzuolana, of conferring moderate hydraulic energy upon common fat lime, and although the activity of cements cannot in any degree be ascribed to its presence since some of the most active contain, of all the compounds of iron together, only a minute proportion; still it is not improbable that ferruginous combinations may be developed, which are well adapted to resist the dissolving power of sea-water.

Influence of molecular condition and heat on the oxide.

Active and inert action.

Forge scales.

297. The gradual and progressive effects of sea-water upon hydraulic mortars immersed in it, notwithstanding the attention which the subject has received from European engineers, is still enveloped in considerable doubt. It is an easy matter to ascertain that its retarding influence upon the initial hydraulic induration is not very great, if the cement be mixed up with fresh water; and it does not become very marked when the cement is both *mixed* with, as well as immersed in sea-water. The strength of mor-

Effect of sea-water on mortars not understood.

tars, however, is considerably impaired by using sea-water for mixing them, as is shown by the following table:

Mixing mortars with sea-water

TABLE IX.

Showing the ultimate strength of rectangular parallelopipeds of mortar $2'' \times 2'' \times 8''$ formed in vertical moulds, under a pressure of thirty-two pounds per square inch, applied at the upper end, until the mortar had "*set*," and broken on supports four inches apart by a pressure from above midway between the points of support. The mortars were kept in a damp place for twenty-four hours, and then immersed and kept in sea-water. Some of the mortars were mixed with fresh water and some with sea-water. The cement was calcined in the Flame Kiln, and the mortars were ninety-five days old.

No. of the mortar.	Composition of the mortar.	Weight in pounds supported before breaking.	Average breaking weight of each kind of mortar.
1	Pure cement mixed with fresh water to a stiff paste	462	
2	" " " "	470	
3	" " " "	573	
4	" " " "	541	
5	" " " "	529	499¼ lbs.
6	" " " "	447	
7	" " " "	510	
8	" " " "	462	
9	Pure cement mixed with sea-water to a stiff paste	322	
10	" " " "	318	
11	" " " "	369	
12	" " " "	353	
13	" " " "	439	379¼ "
14	" " " "	416	
15	" " " "	416	
16	" " " "	400	
17	Cement powder, vol. 1, sand, vol. 2, mixed with fresh water	291	
18	" " " " "	314	
19	" " " " "	267	313⅕ "
20	" " " " "	353	
21	" " " " "	341	
22	Cement powder, vol. 1, sand, vol. 2, mixed with sea-water	181	
23	" " " " "	193	
24	" " " " "	209	195 "
25	" " " " "	197	
26	Cement powder, vol. 1, sand, vol. 2, mixed with sea-water concentrated by heat 25 per cent	165	165 "
27	" " " " "	165	

298. *Preservation of Cement.*—Hydraulic cement exposed

to the air absorbs moisture and carbonic acid gas, and is rapidly deteriorated by the progressive formation of the carbonate and hydro-silicates and aluminates of lime, in the condition of powder. Even when put up in the usual way in the casks ordinarily supplied for that purpose, which are quite as tight as flour barrels, and are always lined throughout with paper, it loses much of its energy in the course of six or eight months, and at the end of fourteen or sixteen months is unfit for use in important works, and is incapable of sustaining the full dose of sand. Cements thus deteriorated are scarcely equal, in hydraulic energy, and in the strength and hardness of the mortars made from them, to those that have been once mixed into mortar, and repulverized at the expiration of three or four days.

Cement deteriorates in air.

Loss of strength by deterioration.

299. When liable to be kept on hand for several months cement should be stored in a tight building, free from any great draught of air through it. If the floor is of earth, or paved with stone, and consequently likely to condense moisture from the atmosphere, the casks should be raised several inches above it. Unground cement in the state of lumps as it leaves the kiln, may be kept for two or three years without sensible deterioration. Circumstances might arise when it would be expedient to pursue this course. In such a case a run of small millstones driven by horse-power, or some other suitable apparatus for pulverizing it as required for use, would have to be provided.

Preservation of cement.

May be kept well in lumps.

300. Cements that contain meagre lime in excess, and border on the intermediate limes, are improved by age to within certain limits. After the lime has had time to slake, or has so far progressed in that operation that the process of mixing up with water will complete it, the deterioration commences and goes rapidly on. The slaking of the lime being due to absorption of mois-

Intermediate limes improved by age to a certain time.

ture, the cement itself receives injury from the same cause, and is degraded in hydraulicity. Several of the layers of the deposit in Ulster Co., N. Y., furnish cements of this type.

Deteriorated cements restored by recalcination.

301. Genuine cements that have been injured by age or exposure, or have from any cause become wet, may be restored to their original energy by re-calcination. For this purpose it is convenient to mix the cement into paste, with about ten per cent. of clay, to secure cohesion, and then form it into balls or cakes of suitable size for burning. It is advantageous to mix the clay, with the water as the first step, as its thorough incorporation with the cement is more readily secured thereby. Cement that has become wet through in the barrels, and taken a "set," as might frequently occur on long sea voyages, may be broken into lumps, reburnt in that condition, and subsequently pulverized. A bright red heat of one and a half to two hours' duration is quite sufficient to restore the activity of injured cements.

Intensity of heat required.

Old mortar from Hoffman's Rosendale cement.

302. Some mortars made from the "Hoffman" brand (paragraph 60), composed of two measures of cement paste and one measure of sand, taken in the summer of 1859 from the Embrasure Target erected at West Point five years previously, was pulverized in a mortar and heated in a crucible for one and a half hours at a bright red heat. It was then mixed into mortar and formed into two cakes. One of these, left in the air, bore the $\frac{1}{12}$ inch testing wire, loaded to $\frac{1}{4}$ pound, in ten minutes, and being then immersed, bore the $\frac{1}{24}$ inch wire and one pound weight in fifteen minutes more; the other, immersed as soon as mixed, sustained the heavy wire in fifty-five minutes, though not very well.

Repulverized cement after two days' setting.

303. Two varieties of cement, viz.: the "Hoffman" and the James River brands, were formed into a paste with fresh water without sand and allowed to harden for three days. They were then repul-

verized and sample-cakes of stiff paste formed. Neither of them would sustain immersion in water at all, but appeared entirely deprived of hydraulicity. The sample left in the air bore the light testing wire in about four hours, but they appeared to have hardened more from the effects of desiccation than hydraulic energy, and fell to pieces soon after immersion in water. Samples restored by a red heat of one hour's duration, were in every respect as energetic as new cements. Numerous trials seemed to indicate that cements repulverized after but twenty-four hours' induration, are scarcely more energetic than those that remained "set" three days.

304. The alkaline silicates were thoroughly tried, as a means of restoring the energy of damaged cements, but without success. The trials of strength were confined mostly to prisms left in the air to harden. The silicate seemed to operate injuriously.

Its strength.

305. Some of this cement mortar, containing no sand, repulverized after three days' "setting," and without having been restored by burning, was mixed with an equal volume of sand, and formed into prisms. Other prisms of like composition were made of the same kinds of cement, fresh from the barrel. The breaking weights of both are given in the following table.

Table X. shows the ultimate strength of rectangular prisms $2'' \times 2'' \times 8''$ of mortar formed in vertical moulds, under a pressure of thirty-two pounds per square inch, applied to the upper end, until the mortar had "set," and broken on supports four inches apart, by pressure midway between the supports. The prisms were kept in sea-water after the first twenty-four hours, and were 320 days old when broken. The cement was measured in powder.

TABLE X.

No. of mortar.	Kind of cement.	Composition of the mortar.	Penetration of point by. 1 impact.	Penetration of point by. 2 impacts.	Weight in lbs. supported before breaking.
1	Hoffman.....	Cement fresh from barrel, vol. 1, sand vol. 1.....	.066	.113	866
2	"	" " "	.072	.117	822
3	"	" " "	.080	.125	806
4	"	" " "	.065	.112	643
5	"	" " "	.072	.122	697
6	"	Cement repulverized after 3 days' set, vol. 1, sand vol. 1....	.075	.127	228
7	"	" " " "	.095	.160	254
8	"	" " " "	.075	.137	248
9	"	" " " "	.090	.159	244
10	"	" " " "	.077	.132	217
11	"	" " " "	.100	.165	228
12	James River.	Cement fresh from barrel, vol. 1, sand vol. 1.....	.050	.077	681
13	"	" " "	.057	.092	623
14	"	" " "	.045	.085	585
15	"	" " "	.057	.092	635
16	"	Cement repulverized after 3 days' set, vol. 1, sand vol. 1....	.097	.165	209
17	"	" " " "	.112	.187	204
18	"	" " " "	.102	.177	271
19	"	" " " "	.112	.187	244
20	"	" " " "	.080	.130	267
21	"	" " " "	.085	.147	296
22	"	" " " "	.097	.145	279
23	"	" " " "	.100	.160	254
24	"	" " " "	—	—	283
25	"	" " " "	.077	.135	306

306. Some of the James River cement, manufactured at a different time, and apparently not as good as that referred to in the foregoing table, was obtained. A few prisms were made of this cement without sand, and while quite fresh. The barrel was then reheaded, and kept for one year without being disturbed, when other prisms were made, also without sand.

Strength of deteriorated James River cement.

Both sets of prisms were kept in water for 320 days, and then broken on supports four inches apart, as usual, with the following results:

The prisms formed of the fresh cement, bore as an average of 6 trials, 402 lbs.
" " " " stale " " " 6 " 244 lbs.

This cement being originally of inferior quality, in consequence probably of careless burning, as well as of a careless selection of stone, the ratio of deterioration is doubtless much less marked than would have been exhibited by a prime article.

Hydraulic lime deteriorates by age.

307. Hydraulic lime also loses its energy by exposure, in the same way as cement.

General Treussart tried some of the Obernai and Metz hydrau-

lic limes. The composition of the raw Obernai stone was lime, .422; magnesia and iron, .050; silex, .105; alumina, .043; carbonic acid and water, .380. The Metz lime burnt contains .683 of lime, .090 of magnesia, .170 of clay, and .057 of oxide of iron. These limes were slaked by an infusion of about ½ of their volume of water. Some of the lime was made into mortar, and formed into prisms, as soon as it was slaked, and while perfectly fresh. Other prisms were formed after the slaked lime had been kept for some time in an uncovered vessel. The ages selected for the lime powder were 15, 25, 30, 45, 60, 90, and 120 days, respectively. The prisms were retained 12 hours in the air, and were then immersed and kept in water. They were broken on supports 4 inches apart, when one year old. The results are given below:

Obernai and Metz hydraulic lime.

TABLE XI.

SHOWING THE STRENGTH OF MORTARS 1 YEAR OLD, IN PRISMS 2″ × 2″ × 6″, BROKEN ON SUPPORTS 4 IN. APART, BY A PRESSURE AT THE MIDDLE POINT.

No of the mortar.	Composition of the mortar.	Breaking weight of the mortars, in pounds. The age of the slaked lime when made into mortar, is given at the heads of the column.							
		Fresh slaked lime.	Slaked 15 days.	Slaked 25 days.	Slaked 1 month.	Slaked 1½ months.	Slaked 2 months.	Slaked 3 months.	Slaked 4 months.
1	Obernai lime in powder.....vol. 1 Sand.....vol. 2	264	121	77	—	77	88	—	—
2	Lime and sand same as above.....	121	132	—	—	—	117	70	66
3	Lime as above.....vol. 1 Sand.....vol. 1 Trass.....vol. 1	473	330	299	—	304	299	—	—
4	Lime, sand, and trass as above.....	209	—	—	389	—	352	317	495
5	Metz lime in powder.....vol. 1 Sand.....vol. 2	116	—	—	44	—	22	—	22
6	Lime as above.....vol. 1 Sand.....vol. 1 Trass.....vol. 1	180*	—	—	312	—	319	—	385

Remarks on the above Table.—We judge from the results given in Table XI. that hydraulic limes deteriorate by the absorption of moisture and carbonic acid gas, if left exposed to the air after slaking;

Deteriorated hydraulic limes and trass.

* This sample was found split longitudinally. The two halves were carefully put together, and the prism broken in that way. The strength must have been diminished by the splitting.

but that the evils of such exposure may be counterbalanced by mixing the deteriorated limes with a suitable proportion of trass. This conclusion might have been arrived at from our knowledge that trass and common lime make a good mortar, and that the practical effect on hydraulic limes, of exposure to the air, is to reduce them to the condition of common lime.

308. General Treussart also found by experiment that the strength of hydraulic limes is injured by air-slaking, in a ratio varying directly with their hydraulicity, but that mortars composed of one measure of powdered air-slaked lime, one measure of sand, and one of trass gave very good results.

Hydraulic limes injured by air-slaking.

CHAPTER VI.

309. CALCAREOUS MORTAR, being composed of one or more of the varieties of lime or cement, natural or artificial, mixed with sand, will vary in its properties with the quality of the lime or cement used, the nature and quantity of sand, and the method of manipulation. No fixed rules for its preparation, that shall be equally well adapted to all the varying circumstances of locality, temperature, and the seasons, can be prescribed.

Calcareous mortars.

310. The objects to be attained by the use of mortar are chiefly of two kinds, as follows:

First, to bind together the solid materials used in masonry constructions; or, in other words, to produce in each particular case, artificial monoliths, of the required form and dimensions.

Their uses.

Second, to form coverings to the solid materials, under the general denomination of stucco work. Under this head may be included all exterior covering, and interior plaster work and ornamentation.

311. Sand exercises no sensible chemical action in the composition and induration of mortars of hydraulic lime; if the sand be silicious, there is believed to ensue a slow formation of silicate of lime, which considerably augments their power of resistance, and in positions excluded from contact with the air, such as the interior of thick walls, becomes an important auxiliary in the hardening process.

Function of the sand.

In a general sense, therefore, any mixture of fragmentary substances, like sand, gravel, pebbles, or pieces of brick or stone, formed into a state of aggregation by a calcareous cementing matter or matrix, might be termed mortar; but as this definition would evidently include concrete or beton, which is made by incorporating into mortar, fragments of brick or of stone, shells and pebbles, it is perhaps well to retain the technical signification of the term *mortar*, by limiting its application to mixtures of sand and a paste of the cementing substances, reserving for a general classification of mortars and concrete under one head, the more comprehensive denomination of *aggregates*.

Technical signification of the term mortar.

Aggregates.

312. The practical strength of aggregates, considered with regard to their tenacity, hardness, and power of resisting compression, depends upon four essentially distinct conditions:

1st. The constant resistance of the parts enveloped by the matrix, whether composed of sand, gravel, pebbles, fragments of brick or stone, or a mixture of them all.

Strength of aggregates.

2d. The resistance varying, and generally increasing with time, of the matrix or cementing matter.

3d. The force of adhesion between the matrix and the other parts, resulting in part, from the former penetrating the interstices of the latter, and in part from the chemical affinities existing between them.

4th. The strength due to the interlacement of the enveloped parts with each other, which produces leverage and friction among them, and enlarges the surface of least resistance.

313. It might be inferred theoretically, that the capacity of an aggregate possessing no voids, to resist any particular kind of strain, cannot surpass that of its matrix or gang; or rather cannot be equal to it, except when the inherent strength of the enveloped parts, as well as the adhesion between them and the matrix, equals or exceeds the resisting power of the latter.

In practice, when these conditions do approximately obtain in exceptional cases, mortars are weakened by the addition of sand or any of the substances above mentioned. These latter have the important effect, however, of preventing or diminishing shrinkage, of hastening the induration of rich limes, and of rendering all kinds of mortars less liable to crack in drying, which is often of very great advantage. They are, moreover, by far the least costly ingredient of mortars, and a due regard to economy compels their use in the largest possible proportions.

Mortars are weakened by the sand used.

Uses of the sand.

314. It might also be inferred that the minimum amount of the cementing material that can be used in any case, is exactly equal to the volume of the voids in the sand, when the latter is well compacted. This theory supposes that there is no shrinkage in the matrix while hardening, and that the manipulation is complete. But as these conditions can never be fully attained in practice, it is unsafe to descend to this inferior limit. Moreover, mortars composed on this principle would be deficient in both *adhesive* and *cohesive* power, from the fact that the particles of sand would present a large area, practically void of matrix, to the surfaces of the solid materials that are to be bound together, and would, for the same reason, be in more or less intimate contact with each other throughout the mass. In order to avoid these defects, it is customary to determine the amount of cementing matter to be used in any particular case, by adding 45 to 50 per cent. to the volume of void space in the sand. One method of ascertaining these voids is, to determine the volume of water which a known volume of the sand (damp and well compacted in a vessel of suitable form) will receive; another, applicable only when all the particles of sand are derived from the same kind of rock, is to ascertain the weight of a known

Theoretical minimum of cementing substances.

Not safely applicable in practice.

Proportion of sand to the *gang* of mortars.

To determine the voids in the sand.

volume of the sand and compare it with the weight of an equal volume of the solid rock, as calculated from its known specific gravity.

315. When sands of various sizes are at hand, a considerable saving of the cementing material may be secured by mixing them together in suitable proportions. To determine this point, take a measure of convenient capacity, say a little more than one cubic foot, and put in it a known volume, say one cubic foot, of the coarsest variety of sand. Then add to it, little by little, so long as there is no augmentation of volume, the sand which stands next in order of size, shaking the vessel well during the operation. Add to this mixture in the same way the other sands in regular order, so long as there is no increase of bulk. The original volume of the coarsest sand, and the several volumes of the other varieties successively added to it, will indicate the proportion in which they should be combined, in order to produce a mixture possessing the smallest measure of void space which they are capable of yielding. Having made the mixture, its voids may be measured by either of the methods given above, or by subtracting from the known voids of the coarsest variety, the difference between the aggregate volume of added sands, and their aggregate voids.

Sands of different sizes can be mixed advantageously.

Computation of the voids of mixed sand.

316. The density of sand depends somewhat on its state of humidity and the manner of measuring it. In determining the properties of the constituent parts of mortars, due allowance should always be made, as ascertained by trial, for these causes of variation. A convenient method of ascertaining the proportion of grains of different sizes in any given kind of sand, with a view to institute a comparison between different varieties, is by using sieves of various degrees of fineness, noting the amount by weight or volume retained by each sieve in succession, commencing with the coarsest. These several amounts, added to that which passes

Sifting the sand.

through the last or finest sieve, should be equal to the known amount taken for trial. Sieves are classified into numbers, which correspond with the number of openings embraced in a lineal inch of the wire gauze of which they are made. Those used in the experiments reported in this work were Nos. 12, 18, 24, 30, 40, 50, and 60. A few of the many sands that have been examined are introduced into the following table, which contains an equal quantity of each kind represented by 1.000.

Classification of series.

TABLE XII.

	No. 1. Calcareous sand, from Key West, Fla.	No. 2. Sand, from Governor's Island, N.Y. Harbor.*	No. 3. Mixed silicious sand.	No. 4. Mortar sand, Fort Richmond.	No. 5. Sand, from Brooklyn, N. Y.
Weight of grains between $\frac{1}{12}$ in. and $\frac{1}{18}$ in. diameter,	.080	——	.140	——	——
Weight of grains between $\frac{1}{18}$ in. and $\frac{1}{24}$ in. diameter,	.138	——	.175	.038	.341
Weight of grains between $\frac{1}{24}$ in. and $\frac{1}{30}$ in. diameter,	.243	——	.584	.092	.302
Weight of grains between $\frac{1}{30}$ in. and $\frac{1}{40}$ in. diameter,	.222	.163	.043	.179	.163
Weight of grains between $\frac{1}{40}$ in. and $\frac{1}{50}$ in. diameter,	.138	.302	.019	.183	.119
Weight of grains between $\frac{1}{50}$ in. and $\frac{1}{60}$ in. diameter,	.103	.352	.008	.224	.060
Weight of grains less than $\frac{1}{60}$ in. diameter,	.076	.183	.031	.284	.015
Total.....	1.000	1.000	1.000	1.000	1.000
Percentage of void space by volume.	——	——	.347	.363	.339
Weight per cubic foot	——	——	106⅓ lbs.	103⅔ lbs.	107¼ lbs.

* This sand is fine grained, containing a very small proportion of particles exceeding one-thirtieth of an inch in diameter, which is in the condition of rather smooth gravel, heterogeneously distributed throughout the mass.

1 cubic foot of sand, No. 3, damp and not compacted, weighed 87 pounds.
1 " " " " damp and compacted, " 97 "
1 " " " " dried in an oven and not comp., " 97½ "

1 cubic foot of sand, No. 3, dried and compacted, weighed 106½ pounds.
1 " " " " comp. and afterwards dampened " 112¾ "
1.11½ cubic feet of loose, damp sand has its volume diminished, by shaking, to 1 cubic foot.
1.09 cubic feet of loose, oven-dried sand has its volume diminished, by shaking, to 1 cubic foot.

METHODS OF SLAKING LIME.

317. Lime is usually sent to market in barrels, either in lumps, as it leaves the kiln, or, in the case of those varieties that are more or less meagre, and consequently difficult to reduce to fine pulp by any of the known methods of slaking, in the condition of coarse powder to which it has been brought by grinding. In either case, it must be slaked before it can be employed as a matrix for mortar.

Condition of lime in the market.

318. Three methods of slaking lime are usually described in works on mortars; on the continent of Europe, the third method, and in the United States, the second and third are seldom resorted to in practice.

Three methods of slaking lime.

319. The first or *ordinary* method termed *drowning*, from the excessive quantity of water sometimes injudiciously employed, consists in pouring upon the lumps of lime, collected together in a layer of uniform depth not exceeding six to eight inches, either in a water-tight wooden box or a basin formed of the sand to be subsequently added in making mortar, and coated over on the inside with lime-paste, to render it impervious to water, a sufficient measure of fresh water,—previously ascertained approximately by trial,—to reduce the whole to the consistency of thick pulp. It is important that all the water required for this purpose, which, with the different limes, will vary from two and a half to three times the volume of the quicklime, should be added at the outset, or, at least, before the temperature becomes sensibly ele-

First method, or drowning.

Add all the water at once.

vated. In this condition the lime will remain entirely submerged, and comparatively quiescent, until after an interval of five to ten minutes, the water becomes gradually heated to the boiling point, when a sudden evolution of vapor, a rapid increase in volume, and a reduction of the lime to pulp, ensues. The increase of volume is sometimes denominated the "growth."

The slaking.

320. This process is liable to great abuse at the hands of workmen, who are apt to use either too much water, thus conferring upon the slaked lime a condition of semi-fluidity, and thereby injuring its binding qualities; or, not having used enough in the first instance, they seek to remedy the error by adding more after the extinction has well progressed, and a portion of the lime is already reduced to powder, thus suddenly depressing the temperature, and chilling the lime, which renders it granular and lumpy.

Abuse of this process.

321. As soon as all the water required has been poured upon the lime, it is recommended to cover up the vessel containing it with canvas or boards, in order to concentrate the heat and the escaping vapor, and direct their action upon the uppermost portions deprived of immediate contact with the water, by the swelling of the portions at the bottom. When it is not practicable to apply this covering, a tolerable substitute is found in the sand to be subsequently added to the mortar. This can be spread over the lime in a layer of uniform thickness, after the slaking has well progressed. Another precaution of equal and perhaps greater importance is, not to stir the lime whilst slaking; but to allow it gradually to absorb the water by capillary attraction and its natural avidity for it, taking care that all portions are supplied with it to that degree requisite to produce a paste of the slaked lime, and not a powder. When the lime is to be used

The slaking lime to be covered up.

Sand may be used for this purpose.

The slaking lime to remain at rest.

for whitewashing or grouting, the water should be added at the outset in larger quantities than specified above, and the whole mass should be run off while hot into tight casks, and covered up to prevent the escape of water.

Lime for whitewashing.

322. In slaking, the essential point is to secure, if possible, the reduction of all the lumps. It will be found difficult to obtain this result with the hydraulic varieties, and the difficulty increases in a direct ratio with the hydraulic energy, until we reach the intermediate limes, or the inferior limit of cement, when the reduction must be effected by mechanical means. Even with those hydraulic limes that do slake, it is often necessary to employ a mortar mill to reduce the lumps,—a condition which should always be secured, as these lumps constitute not only a dangerous substitute for sand, if left intact, but furnish when pulverized, the most energetic portion of the gang.

Hydraulic limes slake with difficulty.

Mechanical means sometimes employed for reducing them.

323. *Slaking by Immersion.*—The second method of slaking (*by immersion*), consists in suspending the quicklime, previously broken into pieces of about the size of a walnut, and placed in a basket or other suitable contrivance, in water, for one or two minutes, taking care to withdraw it before the reduction commences. The lime should then be quickly heaped together, or emptied into casks or bins, and covered up, in order to concentrate the heat and prevent the escape of vapor. In this condition it soon begins to swell and crack, and finally becomes reduced to a fine powder, which may be preserved several months without serious deterioration, if packed in casks, and kept from direct contact with the atmosphere. The expense which would ordinarily attend the practical application of this process, and the difficulty, and even impossibility of securing with certainty, at the hands of workmen, the period of immersion, have led to

Second process of slaking.

Precautions.

This process expensive and difficult.

a modification of it, which consists in sprinkling the broken fragments formed into heaps of suitable size, with one-fourth to one-third of their volume of water. This should be applied from the rose of a finely gauged watering-pot, after which the lime should be immediately covered with the sand to be used in the mortar. In this condition it should not be disturbed for at least a day or two, and the opinion prevails in the southern portions of the continent of Europe that the quality of the lime is improved by allowing the heaps to remain several months, without any other protection from the inclemency of the weather than an ordinary shed, open on the sides. In the vicinity of Lyons this custom very generally obtains, the autumn being usually selected for slaking all the lime required for the following season's operation. In Europe, this method of slaking is applied to the fat and slightly hydraulic limes only, and not to those that are eminently hydraulic, upon which it seems to act disadvantageously, by depriving them, in a measure, of their hydraulic energy.

A modification of it.

Practice in Europe.

324. *Spontaneous slaking.*—Quicklime has a great avidity for water, and when not secured from direct contact with the atmosphere, gradually absorbs moisture from it and falls into powder, exhibiting but very slightly, and sometimes not at all, the other phenomena usually developed in slaking. The lime is then said to be slaked *spontaneously*, or *air slaked.*

Third process—Spontaneous or "air" slaking.

325. It has been claimed by some engineers that this method, if the precaution be taken to stir the lime frequently, so as to expose every portion of it to direct contact with the air, confers a slight degree of hydraulicity upon fat lime; and Culmann, in his "Cours sur les Chaux, Mortiers, et Mastics" says, "it produces very advantageous results upon fat or feebly hydraulic limes that are to be mixed with pozzuolana and used under water." It

Thought to confer hydraulicity in a slight degree.

Opinion of Culmann needs confirmation.

is believed that both of these statements need confirmation. A great and insurmountable objection to the process, however, is the expense of storage room or sheds which it necessarily involves, to say nothing of the time required for its completion. Spread out in layers of from ten to twelve inches in depth, some varieties of fat lime might become thoroughly reduced in twenty or twenty-five days; others would require as many weeks; while with a few, the process would continue for a whole year. Hydraulic limes are greatly injured by spontaneous slaking. Fat limes slaked to powder by the second or third process, are converted into paste with less water, and undergo a less augmentation of their original volume, than when slaked by the first process.

Inconveniences of third process.

Hydraulic limes injured by it.

Remarks.

326. By neither of the three processes of slaking, nor any modification of them, have I succeeded in obtaining as great an augmentation of the volume of fat lime measured in the state of paste, as is stated by M. Vicat to belong to the fat limes of France, viz.: that one volume of the quicklime in lumps, by the absorption of 2.91 volumes of water, will give 3.5 volumes of paste.

According to the same authority, these limes slaked by immersion to powder, and afterwards reduced to paste, absorb 1.72 of water, giving 2.34 of paste; while, by spontaneous slaking they required 1.88 of water, and gave 2.58 of paste. It is also stated that the hydraulic limes in slaking absorb 1.05 volumes of water by the first process, .71 by the second, and .68 by the third, producing respectively 1.37, 1.27, and 1.00 volumes of paste.

M. Vicat's deductions.

Increase of volume.

327. I have repeatedly tried all the limes offered to any extent, in the New York market. In slaking them, quantities of five to ten pounds were generally employed; and the utmost care was taken, in all cases, to obtain perfect accuracy in the weights and meas-

Experiments in slaking American limes.

urements, and by the use of glass and tin vessels to prevent the waste or absorption of water. The glass vessels found most convenient were two cylindrical jars, one eight inches in diameter and eighteen inches deep, and the other three inches in diameter and ten inches deep. They were accurately ground off at the bottom to a plane surface at right angles to the axis, so as to stand in a vertical position on a horizontal surface, and were graduated to cubic inches, and the small one to fractions of an inch throughout their entire length. The large jar was used for determining the volume of the quicklime and of the resulting powder or paste; the small one, for measuring the water absorbed in slaking. When the quicklime to be tried was in the condition of lumps, the usual process of ascertaining its volume by the displacement of sand was employed.

Vessels used.

328. To hold the lime while slaking, tin cans about one foot square and one foot deep, were found to answer a good purpose.

329. General Totten, from an average of many trials at Fort Adams, states that one volume of quicklime slaked with $\frac{1}{2}$ its volume of water gave an average of 2.27 of powder; $\frac{3}{8}$ of water gave 1.74; $\frac{3}{4}$ gave 1.81, while equal volumes gave 2.06. Slaked by drowning, 2.54 volumes of water gave 2.68 of thin paste; and by sprinkling, 1.70 of water gave 1.98 of thin paste. Mixing the powder with .40 of water gave .66 of thick paste, while .50 gave .76 of thinner paste. One volume of lime slaked spontaneously produced 1.84 of powder, and one volume of this powder and .50 of water gave .75 of thin paste. One volume of quicklime when pulverized, gave .90 of powdered quicklime.

Results of Gen. Totten's experiments.

Increase of volume.

330. TABLE XIII.

Shows the results obtained by many trials of slaking applied to the limes in common use in the United States:

No. of the trial.	Kind of lime used.	Before slaking. Weight, in pounds.	Before slaking. Volume, in cubic inches.	Volume of water absorbed, in cubic inches.	After slaking. Weight, in pounds.	After slaking. Volume, in cubic inches of paste.	Ratio of increase. In weight.	Ratio of increase. In volume.
1	Rockland lump lime.....	5	91.2	——	11.19	224.2	2.24	2.46+
2	" " "	5	86.5	235.6	11.78	245.1	2.36	2.83+
3	" " "	5	91.2	209.8	13.25	292.6	2.65	3.21—
4	" " "	5	95.0	182.4	11.06+	227.0	2.21+	2.40
5	Sing Sing lump lime from Sing Sing marble.....	5	87.4	210.0	11.12	227.0	2.22+	2.61—
6	" " "	5	89.3	——	11.78	248.9	2.36—	2.79—
7	" " "	5	88.4	197.6	10.67	225.1	2.13+	2.56—
8	Rondout ground lime.....	5	110.2 well shaken.	195.7	10.52	222.3	2.12+	2.00+
9	" " "	5	110.2 well shaken.	201.4	11.37	239.6	2.27+	2.14
10	" " "	5	115.9 well shaken.	247.0	——	281.2	——	2.42+
11	" " "	5	124.5 well shaken.	209.0	11.37+	248.9	2.27+	2.00
12	" " "	5	124.5 well shaken.	209.0	11.44—	249.9	2.29—	2.00+
13	" " "	5	128.3 well shaken.	197.6	11.25	247.0	2.25	1.93—
14	Glen's Falls lime in lumps.....	5	93.1	269.8	13.33	285.0	2.66+	3.06+
15	" " "	5	93.1	267.9	12.44	271.7	2.49—	2.92—
16	" " "	5	93.1	279.3	13.50	304.0	2.70	3.26+
17	" " " slaked by immersion.....	5	91.2	51.2 to produce a powder.	6.19 of powder.	260.3 of powder.	1.24 for powder	2.86 for powder
				181.5 to produce a paste.	10.50 of paste.	202.8 of paste.	2.10 for paste.	2.54 for paste.
18	" " " "	5	87.4	68.4 to produce a powder.	6.62+ of powder.	285.0 of powder.	——	——
				201.4 to produce a paste.	10.87+ of paste.	224.2 of paste.	——	——

EXPLANATION OF THE ABOVE TABLE.

No. 1. About one-half the quantity of water mentioned was poured on at once, and the balance gradually, with occasional stirring.

No. 2. Most of the water was poured on at the outset, and the lime was stirred occasionally.

No. 3. All the water (269.8 cubic inches) was poured on at once, submerging the lime completely, in which condition it was left covered up for several hours without being agitated at all.

No. 4. 83½ cubic inches were first added, and the balance of the 182.4 inches gradually, with occasional stirring.

No. 5. The water was poured on gradually, with occasional stirring.

No. 6. The lime was nearly covered up with the water at the outset. When the slaking had well progressed, more was added, with occasional stirring.

No. 7. Water poured on gradually, with occasional stirring.

No. 8. do. do. do. do.

No. 9. All the water was poured on at the outset, and after the expiration of one hour, the lime was stirred.

No. 10. All the water was poured on at once, and the canvas was covered up, and not disturbed until the next day. The paste was very thin and of the consistency of cream.

No. 11. Water all poured on, and the can covered as before. The paste was much stiffer than No. 10, but rather less so than most of the foregoing.

No. 12. Water poured on as above, and not disturbed until the following day. The paste was not quite so thin as No. 10, but much more so than No. 11.

No. 13. Water all poured on, and the can covered as above. The paste was a trifle less stiff than that adopted as the standard in these comparisons.

No. 14. The lime was broken into pieces of 1 to 1½ inch cube, and 209 cubic inches of water poured on at once. The can was then covered up with canvas and left for several hours, until it had become cool. The lime was then in the condition of a powder, requiring $60\frac{8}{10}$ cubic inches of water to reduce it to a paste of the requisite consistency.

No. 15. The lime was broken up as above, and 83½ cubic inches poured over it at the outset. The can was left open, and the balance of the water added in quantities of 20 to 24 cubic inches at a time, until 211 cubic inches had been used. This was just enough to produce a damp powder which required $56\frac{9}{10}$ cubic inches more to bring it to a paste.

No. 16. The lime was broken up as in No. 14, and submerged in 270 cubic inches of water. The can was then covered, and not disturbed until after the expiration of four hours. $9\frac{3}{10}$ inches of water were added to produce the requisite degree of consistency.

No. 17. The lime, broken as in No. 14, was placed in a basket and suspended one minute in water, of which it absorbed $51\frac{2}{10}$ cubic inches. It was then poured into a can, covered up, and not disturbed until the next day, when it was found to be reduced to a powder containing about ten per cent. of small lumps. After these were pulverized, $130\frac{5}{10}$ cubic inches of water brought the whole to a stiff paste.

No. 18. The lime, broken as above, was suspended in water 1¾ minutes, and was then poured quickly into a can, and kept covered up until next day, when it was found very well slaked, with very few lumps, and none but what could easily be rubbed fine under a spatula.

331. *Action of the hydrates in the air.*—A paste of the hydrate of fat lime in free contact with the atmosphere, absorbs carbonic acid gas upon the surface, although not to the point of complete saturation, and becomes coated with a mixture of hydrate and carbonate of lime, ($CaO.CO_2+CaO.HO$). The gas gradually penetrates the substance, at a rate of progress constantly on the decrease, and at the end of one year, according

Hydrate of fat lime in the air.

to M. Vicat, the layer of impure carbonate is from .10 to .12 of an inch in depth. The same authority says, that the absorption and penetration of this gas proceeds more rapidly in the hydraulic limes than in the fat limes—a statement which not only needs confirmation, but is believed to be the converse of what is true. My researches lead me to the same results as those enunciated by Geo. Robertson, Esq., in a paper recently read before the "Royal Society of Edinburgh," viz.: "*The depth to which carbonic acid is absorbed into mortar in a given time, and, to a certain extent, the induration from that cause varies inversely with the hydraulic properties of the lime, which depend upon the silica contained in it.*"

Absorbs carbonic acid gas.

Ratio of absorption among the different limes inversely as their hydraulicity.

332. The incrustation is due in the case of hydraulic limes to the combined influence of reactions, considerably more complicated and obscure than those which obtain with the hydrate of fat lime. The hydrosilicate and aluminate of lime (SiO_3 + CaO + 6 HO) and (Al_2O_3 + 3 CaO + 6 HO) are formed in addition to the hydrocarbonate. The formation of these compounds of silica and alumina is not confined to the crust on the surface, but takes place throughout the mass, and is really the principal efficient cause of the induration of this class of limes, when placed under water, or in humid localities excluded from atmospheric influences. It appears not improbable that these circumstances attending the superficial induration of hydraulic limes in the atmosphere, have led to errors in measuring the depth of the covering of subcarbonate, owing to the difficulty in determining with precision the exact position of the surface which separates the crust formed by the combined influence of exterior and interior causes, from those portions in which the induration is entirely independent of atmospheric influences.

The covering of subcarbonate formed.

Other compounds formed.

Difficult to measure the subcarbonate covering.

333. The hardness assumed by the hydrate *in the air* is intimately connected with the process of slaking, and appears to sustain a direct ratio with the increase in volume. The three modes of slaking arranged in order of their superiority in this respect stand as follows:

Relation between hardness of hydrate and mode of slaking.

1st. For fat limes: ordinary slaking, spontaneous slaking, slaking by immersion.

2d. For hydraulic limes: ordinary slaking, slaking by immersion, spontaneous slaking.

334. The hydrates of fat lime, drying in the air, shrink and crack to such an extent, that they cannot be employed in mortar for masonry without a large dose of sand.

335. *Action of the hydrate under water.*—The hydrate of fat lime is soluble to the last degree in water frequently renewed. Immersed in the condition of stiff paste in still water, it absorbs a certain quantity of the fluid, without any augmentation of volume, or sensible change of consistency. The amount thus absorbed depends upon the mode of slaking. A paste formed by the *ordinary* or *first* process takes up .04 of water; if slaked by *immersion*, nearly .11; and if *air*-slaked, .245. An increase in density ensues, varying with the amount of water absorbed, and we might therefore be justified in assuming that fat limes slaked by the second or third process, which are to be rendered hydraulic by the addition of natural or artificial pozzuolana, or cement, would be superior to those slaked by the first process, on account of the more intimate contact between the ingredients, and consequently, the more favorable condition for combination developed by the interior compression due to this increase of density.

Hydrate of lime soluble in water frequently changed. It absorbs water.

Mixed with pozzuolana, or cement.

We would also suppose that the same assumption would be justified, in the case of hydraulic limes which are to receive additions of pozzuolana. This

Hydraulic limes and pozzuolana.

theory is not fully confirmed by experience, which shows that the latter class, when they are to be mixed with pozzuolana, may be slaked by either the first or second process, with similar results, and that the third process should invariably be proscribed. When they are to be combined with inert sand only, they should be slaked by the first process.

336. For fat limes, the second and third methods have been supposed by many engineers to possess some advantage; the former, in conferring increased hardness and tenacity upon the mortar; the latter as a means of securing hydraulic properties in a moderate degree; but as there are some doubts upon these points, particularly as to the alleged superiority of air-slaking, and as any requisite degree of strength, hydraulic energy and quickness may be conferred upon lime mortars with more certainty and with equal economy, by the judicious use of hydraulic agents, either natural or artificial hydraulic lime, pozzuolana, or cement, (particularly the latter in the United States,) the first mode of slaking, inasmuch as it is attended with less original outlay, gives more certain results, and requires fewer precautions at the hands of the workman, may be regarded as the most advantageous in nearly every case, *provided the precaution is taken to pour on at the outset all the water required to produce a stiff paste*, but no more.

Supposed advantage of the second and third process for fat limes.

That of the third process unimportant in the United States.

The first process the most advantageous.

337. For slaking lime, fresh water should be used, sea-water giving in all cases greatly diminished volumes.

Use fresh water for slaking.

338. General Totten announced the following as the results of experiments made at Fort Adams, upon the different modes of extinction:

1st. Slaking by drowning, or using a large quantity of water in the process of slaking, affords weaker mortars than slaking by sprinkling.

The "drowning" process weakens the lime.

Air-slaked lime unsatisfactory.

2d. Experiments with air-slaked lime were too few to be decisive, but the results were unfavorable to that mode of slaking.

339. *Preservation of Lime.*—The paste of fat lime, whatever may have been the mode of extinction, may be preserved intact for an indefinite length of time, if kept from contact with the air. It is usual to put it in tight casks, or in reservoirs or trenches covered up with sand; or, when shed-room is available, to form it into rounded heaps similarly protected and under cover.

Preservation of lime paste.

340. The powder derived from the second and third modes of extinction may be preserved for several months, without sensible deterioration, in covered casks or bins, or if heaped up in dry sheds, and covered over with straw, cloth, or dry sand.

Preservation of lime powder.

341. Until quite recently, opinions among engineers were divided as to the effect of time upon the quality of paste of fat lime, preserved with suitable precautions for future consumption. General Treussart entertained the opinion that they should be made into mortar and used soon after their extinction. This idea finds few advocates at the present day, although the practice in this country conforms to it with singular unanimity. As before observed, it is customary in some parts of the continent of Europe to slake the lime the season before it is to be used.

Gen. Treussart.

Practice at the present day.

342. *Fabrication of Mortars.*—The relative quantities in which sand and the cementing substance, whether the latter be derived from common or hydraulic lime, or cement, should exist in mortar, depend in a great measure on the character of the work in which it is to be used; its locality and position with regard to a state of moisture or dryness; and, if subjected to alternations in this respect, the character of the moisture, depending on its proximity to or remoteness from

Fabrication of mortars.

The proportion of the ingredients vary with circumstances.

the sea, the nature and magnitude of the forces which it will be required to resist, the peculiarities of the climate, and the season of the year in which the work is to be performed.

343. In practice, the actual quantities of the different ingredients to be portioned out "depend on the varying conditions of dampness and dryness, looseness and compactness, powder and paste, in which they may be measured."

344. The following data, derived from the work of General Totten and from direct trials, will be found useful in estimating the amounts of the different ingredients necessary to produce any required quantity of mortar.

One cask of lime.

One cask = 240 lbs. of lime, will make from 7.80 to 8.15 cubic feet of stiff paste.

One cask of cement.

One cask *= 308 lbs. of finely ground cement, will make from 3.70 to 3.75 cubic feet of stiff paste; 79 to 83 lbs. of cement powder will make about one cubic foot of stiff paste.

One cubic foot of cement powder.

One cubic foot of dry cement, shaken down, but not compressed, mixed with .33 cubic feet of water (about $2\frac{1}{2}$ gallons), will give .63 to .63$\frac{1}{2}$ cubic feet of stiff paste (about $4\frac{7}{10}$ gallons).

One cubic foot of dry cement powder, measured loosely and without any compression, will measure only .78 to .80 cubic feet, if packed (as at the manufactories) with a wedge-shaped stick or paddle. The data given in the following table (XIV.) are compiled from General Totten's work. The quantities are represented by volume.

*300 lbs. net is the standard barrel, but it usually overruns about eight lbs.

UNIVERSITY Library. Of California.

TABLE XIV.

Lime in thin paste.	Cement paste.	Sand well compacted.	Mortar produced.
1	.00	1.92	..... 2.25
1	.00	1.00	..... 1.71
1	.00	.50	..... 1.07
1	.45	1.82	..... 2.49
1	.69	1.39	..... 2.22
1	.25	1.00	..... 1.85
1	.68	.91	..... 1.95
1	.18	.71	..... 1.57
1	.78	.78	..... 1.84
1	.00	2.00	..... .64 water made 2.54 grout.
1	.25	2.00	..... .92 " " 3.10 "
1	.75	2.00	..... 1.04 " " 3.56 "
1	1.00	2.00	..... 1.22 " " 3.76 "
		2.02	of mortar with .87 " " 2.90 "
		2.13	" " .87 " " 3.05 "
		4.30	" " 1.80 " " 6.04 "
		4.67	" " 2.01 " " 6.60 "
		4.30	" " 1.80 " " 6.20 "
		4.95	" " 1.76 " " 6.64 "
		5.53	" " 1.80 " " 7.11 "

345. When mortar is to be made in quantities sufficiently large to warrant the expense, a mortar mill of some approved pattern should be provided, for incorporating the ingredients, as the mortar thus obtained is invariably superior to that produced by the use of the hoe and shovel only.

346. *The mill used at Fort Warren*, Boston harbor, during the construction of that work by Col. Thayer, of which a vertical section through the centre of motion is given in Fig. 33, is thus described by Lieut. W. H. Wright, in his "Treatise on Mortars," page 98: "It consists of a circular trench built of masonry, with sloping sides. In the trench rests a heavy wheel, 8 feet in diameter, furnished with a tire $\frac{1}{2}$ inch thick and 12 inches broad, and loaded by having its interior space filled with sand. At the centre of motion is a drum, or circular mass of masonry, 4 ft. 8 in. in diameter, in which is firmly fixed a vertical axis about 8 inches square. With this axis is connected the horizontal shaft (also about 8 inches square), which

Description of mortar mill driven by horse-power.

passes through the centre of the wheel, and to which the horse is attached.

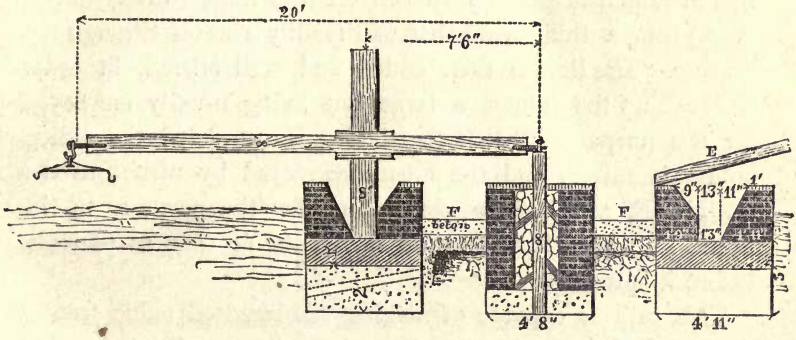


Fig. 33.

"The distance from the centre of motion to the centre of the wheel or trench is 7 ft. 6 in., and the radius of the horse-path is 20 ft.

"The space comprised between the drum and trench is used as a reservoir for the slaked lime. It is sufficiently capacious to contain the paste which sixteen casks of lime will afford, and is conveniently divided, by means of movable radial partitions, into sixteen equal parts; so that the laborer, who prepares the mortar, is relieved of the necessity of measuring the paste.

Description, continued.

"The mill is protected from the weather by a cheap roof; it is placed in the vicinity of a pump, immediately under the spout of which stands a box, 7 ft. long, 5 ft. broad, 1 ft. 4½ inches deep, used for slaking the lime. This box is connected at one extremity with a small compartment, in the bottom of which is an iron grating, which allows the fluid paste to pass out into the reservoir, but retains the stones and imperfectly slaked lumps of lime. During the process of slaking, the compartment is separated from the rest of the box by a

movable board, which slides in grooves made water-tight with a little of the lime putty.

"The board being in its place, water is pumped into the box in sufficient quantity to convert the lime, (three casks at once,) into a thin cream that will readily run off through the grating. The lime is then added and well stirred, in order to break up the lumps, a large hoe being usually employed for the purpose. When the slaking is completed, the sliding board is raised, and the cream conveyed by means of the trough, E, attached to the grating for the purpose, to the basin, F, where it is allowed to remain as long as possible before it is used."

Capacity of mill.

This mill is capable of making six hundred cubic feet of mortar per day of ten hours. By increasing the radius of the trench to 12½ ft., and the radius of the horse-path to 25 ft., the working capacity of the mill would be nearly, if not quite, doubled.

Other implements required.

347. The other implements that will be found convenient in the preparation of mortar are a hoe and shovel, differing little, if at all, from the ordinary form; a box for measuring lime and cement paste, which should be of convenient capacity, say 3 cubic feet, and should be arranged with handles projecting horizontally on two opposite sides, like those of a hand-barrow, and a second box of the same size as the foregoing, or rather a little larger (say 3½ cubic feet in capacity), so that it will contain, loosely thrown in and struck, a volume of sand corresponding to three cubic feet well compacted. This box may be provided with handles like the other, but had better be arranged on a wheel-barrow.

Process of making mortar.

348. To make mortar with the mill above described, the lime paste is first put into the trench from one of the central compartments. To this is added by measurements from the wheel-barrow box, about one-half of the sand required for the batch, and the mill

is then set in motion, and the ingredients thoroughly incorporated. The remainder of the sand then follows, with such additions of water as may be necessary to bring the mass to the proper consistency. When lime mortar is to be rendered hydraulic by the use of cement or of an alkaline silicate, these had better be added—the cement in powder and the silicate in solution—to the lime paste just before the mill is set in motion, in order that the mixing may be thorough and complete; except in the case of very quick-setting cement, when its incorporation into the mortar should be deferred until the last portions of sand are added.

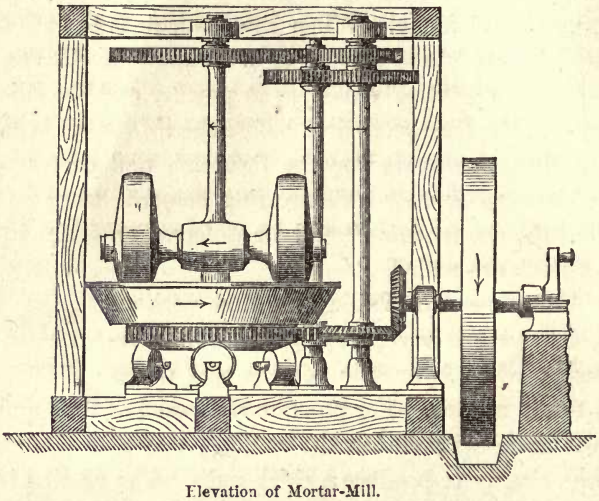
Excess of water not used in slaking.

349. This process of slaking the lime with an excess of water was never employed at Fort Warren, except when hydraulic cement was to be added to the mortar. For mortars composed of lime and sand only, the lime was slaked in the ordinary way with a sufficiency of water, simply to produce a thick pulp. The result given in Table XIII., page 185, which may be easily verified on a large scale, indicate, apparently beyond a doubt, that with the limes most extensively in use for public works on our Atlantic coast, the largest augmentation of volume in slaking is secured by adhering to the following directions, viz.: put the lime into a box, break up the larger lumps with a hammer; pour in at once the quantity of water (ascertained previously by trial) necessary to reduce them to a stiff paste, and then cover up the box so as to prevent, as much as possible, the escape of heat and vapor, allowing it to remain in that condition, without stirring, until the reduction is complete. In order to connect this process with the operations of a mortar-mill, it might be necessary to provide several boxes, so that the lime might, in all cases, have at least forty-eight hours to digest before it is made into mortar.

Precautions to be used in slaking.

350. Major E. B. Hunt, Corps of Engineers, formerly charged with the construction of Fort Taylor, Key West,

Florida, has kindly furnished me the following description of the steam mortar-mill in use at that work.

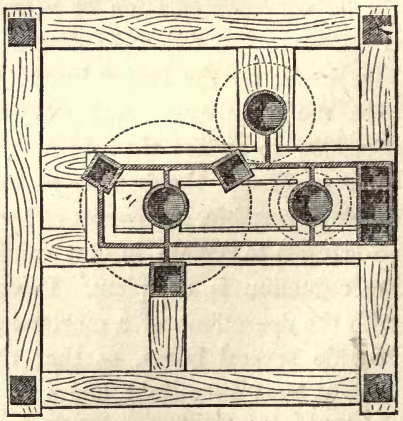


Elevation of Mortar-Mill.

Fig. 34.

351. *The steam mortar-mill* which was erected at Fort Taylor in 1857, is of the kind devised by the late Brevet-Major J. Sanders, and was purchased and set up under his direction. The mill and engine were made by E. C. Stotsenberg, Wilmington, Delaware, and cost $3.466. The frame and house for the mill, and setting them up cost $237, to which should be added the freight and cost of engine-house, making

Steam mortar-mill.



Plan of bed-plate; scale ¼ in. to 1 foot.

Fig. 35.

nearly $5,000 as the cost of the whole in working order. The engine is about sixteen to twenty horse-power, and has a heavy fly-wheel. Two-thirds of this power would run the mill, though at greater cost for fuel and at higher pressure. The engine is geared into a fixed connection with the mortar-mill, which is a fault, as the engine cannot be used for any other purpose, without driving the mill,

Description of same.

The mill, Figs. 34 and 35, consists essentially of a pan geared into a cogged connection with the engine, and supported on large conical bed rollers; and of a pair of hollow cast-iron wheels, so joined by an axle, that they revolve in the opposite sides of the pan with the same velocity as the pan itself. The grinding surfaces have thus a compound or double velocity. Two helical scrapers are fixed to the vertical driving shaft of the wheels, and are so shaped as to throw a sort of furrow in the mortar materials when mixing. A scraper is fixed to each end of the horizontal shaft, so as to scrape the faces of the large wheels as they roll around that shaft. Another scraper is also fixed to this axle, so as to scrape the inner face of the pan and to throw a furrow towards the centre.

The lime paste is first put in the pan, and is ground while the sand and cement are measured out, on a fixed platform at the level of the bottom of the pan and bordered up close to its rim. The mixed cement and sand are shovelled in, and water added until the whole batch is introduced. The greatest resistance is encountered when the dry materials are thrown in, at which time the speed is very much slackened, and the engine requires nearly its full power at the working pressure, if the filling be done very rapidly. As the mixing proceeds, the speed of revolution quickens greatly, but is controlled by the engine-driver in proper limits.

Manner of using the mill.

When the batch is sufficiently ground and mixed, it is scooped out by the use of a scoop-shovel, the workman standing on a lower portion of the platform, about a foot below the

bottom of the pan, and throwing the mortar into a mortar-box which is backed in by a sling cart, so arranged as to carry the batch to the derrick or point of use, and then to run the box down to the ground by two screws with arms and long links, one at the fore and one at the near end of the box. Each batch of mortar corresponds to one barrel of cement, and the mill has repeatedly made over fifty batches in a day, and can do this as a regular day's work. It requires one engine-driver, one fireman, and from two to five men at the mill, according to the amount of mortar to be made. It has also been used during the last and present season to make the mortar for concrete, which is transported by the sling cart, hoisted by the derrick on the concrete platform, and then thrown over the broken stone spread out to receive it. Two turnings* mixed it very well. The broken stone is hoisted by a light platform carrying five barrels, the usual amount for a batch. This using it for concrete as well as for masonry mortar, will often make running the mill an economy, when it would not be so, were only the mortar for masons made there. It will hardly be found an economy, to run the mill for less than twenty to twenty-five batches a day.

Force required to work the mill.

The mortar made in this mill is very much better than that made by hand from the material found at Key West, as the coarse calcareous sand requires pulverization to make the mortar work well. It is what the masons call "woolly," when made by hand, and requires a much larger dose of cement or lime, to work properly under the trowel.

Quality of mill-made mortar.

The brick-work joints with mill-made mortar are observably thinner than with the hand-made mortar, thus giving a saving of mortar per cubic yard.

The gain by using the mill, is rather in the superior qual-

* These turnings are described in the third step of the method of manipulation practised at Forts Richmond and Tompkins, New York. (Paragraph 369.)

ity and saving of quantity of the mortar, than in the cost of mixing, though, when large operatives are steadily maintained, there is a great gain under this head, when circumstances favor its easy distribution. Advantage of the mill.

Ordinarily, a batch needs to be ground not less than seven minutes, and not beyond fifteen minutes from the time the lime paste is put in the pan. If the grinding be carried much beyond this time, the mortar is decidedly impaired, and sets very slowly. This is ascribed, in part, by Major Hunt to the extreme pulverization of the calcareous sand, whereby the void spaces are made all small and nearly uniform, and partly to the incessant breaking up of the incipient setting by long continued grinding." Time required in making mortar with the mill.

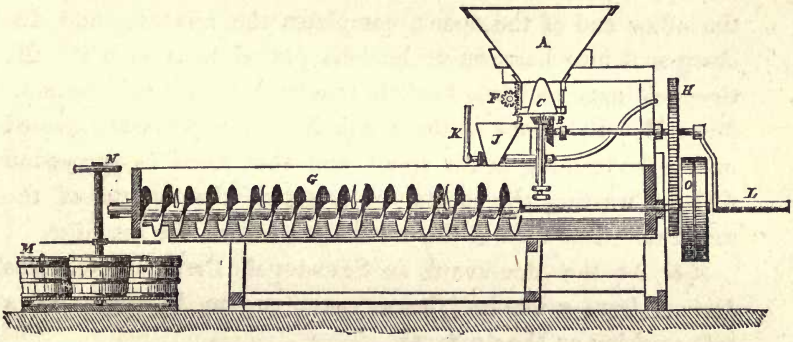


Fig. 36.

352. *Another mortar-mill*, successfully used by the designer, M. Greyveldinger, on the works connected with the drainage of the Boulevard de Sevastopol, Paris, is represented by Fig. 36; it consists of a hopper of sheet-iron, A, closed at the bottom by a disk, B, surmounted with a cone, C; the disk and cone receive a rapid, rotary motion by means of the cogwheel D. The hopper is provided with a rectangular opening, E, $\frac{1}{2}$ of a metre (7.9 inches) in width, and of which the height can be varied at M. Greyveldinger's mill.

pleasure by means of a sheet-iron slide controlled by a ratchet and cog-wheel, F. Below the hopper, is a cylindrical spout, G, containing a revolving screw, to the core of which, iron points are attached at regular intervals. Jets of water regulated at pleasure by hand, by means of the stop-cock K, are let into the funnel J, at the bottom, through a hose leading to a reservoir of water.

353. The dry ingredients of the mortar having first been roughly mixed with a shovel, and if necessary, passed through a screen, are introduced into the hopper. The rotation of the disk and cone completes the incorporation of the dry materials, and imparts to them a centrifugal motion which insures a constant flow from the opening E, into the funnel J, where they receive the requisite supply of water, and pass into the spout G. The motion of the screw carries the mortar to the other end of the spout, completes the mixture, and discharges it into barrows or buckets placed to receive it. M. Greyveldinger had four buckets arranged on a revolving platform, M. By means of the crank N, the buckets are passed under the opening in the spout, and thus filled in succession without wasting the mortar or arresting the motion of the machine. Two men at the crank L, can work the machine.

354. At the Boulevard de Sevastopol, Paris, motion was derived from a one-half horse-power engine, by means of a belt working on the drum, O.

Force required to tend it.

355. There were required to tend the machine eight laborers, to measure the materials, fill the hopper, take away the mortar, &c., one intelligent foreman to regulate the opening in the hopper and the supply of water, and one engineer.

356. The average daily expense, neglecting the wear and tear, is as follows:

Nine men at three francs - - -	fr. 27
One engineer, - - - - -	4
Coal - - - - - - - -	2
	33=$6.10

357. The capacity of the machine was thirty cubic metres (38.3 cubic yards) of mortar, per day, of ten hours. Cost of making one cubic metre, 1.10 fr., and of one cubic yard, sixteen cents. Its capacity.

358. Estimating the laborers at ninety-one cents per day, the engineer at $1.50, and supposing the other expenses to remain the same, the cost of making one cubic yard of mortar would be twenty-eight cents. The cost of making the mortar at Fort Warren, with the mill consisting of a heavy wheel turning in a circular trough by horse-power, and labor at ninety-one cents per day, was thirty-nine cents per cubic yard. Mr. G.'s mill will answer for the quickest setting cements, as only eight seconds of time elapse after the materials receive the water, before the mortar is discharged into the buckets. Cost of making mortar with it.

359. Extensive operations requiring large quantities of mortar are frequently carried on by experienced engineers, without the aid of a mortar-mill of any kind. When ordinary lime mortars are thus made by hand, it is customary and convenient to slake the lime by the first method described, and in no greater quantity than may be required for immediate use. The operation should be conducted under a shed. The measure of sand required for the "batch" is first placed upon the floor, and formed into a basin for the reception of the unslaked lime. After this the latter is put in, and the larger lumps broken up with a mallet or hammer; the quantity of water necessary to form a stiff paste is let on, from the nozzle of a hose, or with watering-pots, or even ordinary buckets. The lime is then stirred with a hoe, as long as there is any evolution of vapor, after which the ingredients are well mixed together Making mortar by hand. Ordinary method of slaking lime.

with the shovel and hoe, a little water being added occasionally if the mass be too stiff. At this stage of the operation, it is customary to heap the mortar compactly together, and allow it to remain until required for use. When circumstances admit, it should not be disturbed for several days, and during the period of its consumption should be broken down and "tempered" in no larger quantities than may be required for use from day to day.

Slight modifications recommended.

360. It is believed that certain slight modifications of this common method of procedure can be made, with decided advantage in the final results. They may be indicated as follows:

361. *First.* All the lime necessary for any required quantity of mortar should be slaked at least one day before it is incorporated with the sand.

Slake the lime at least one day before it is wanted.

362. *Second.* The sand-basin, to receive the unslaked lime should be coated over on the inside with lime-paste, to prevent the escape of water.

In a water-tight basin.

All the necessary water to be poured on at once.

363. *Third.* All the water required to slake the lime to a stiff paste, should be poured on at once. This will completely submerge the quicklime. The heap should then be covered over with tarpaulin or old canvas, and left until next day.

Mix ingredients, and heap up for use.

364. *Fourth.* The ingredients should be thoroughly mixed, and the mortar heaped up for future use.

365. The mortar used by Lieut.-Col. J. G. Barnard, Corps of Engineers, in the construction of Forts Richmond and Tompkins, New York harbor, was made by hand. When required for stone masonry, or concrete, it was composed of hydraulic cement and sand, without lime.

366. *Each batch of mortar, or concrete, corresponded to one

* These data were furnished by Captain M. D. McAlester, of the Engineers, at that time Assistant to Lieutenant-Colonel Barnard, Corps of Engineers.

cask, or 308 pounds net, of hydraulic cement powder. Four men constituted a gang for measuring out and mixing the ingredients, who proceeded to the several steps of the process in the following order:

Method of manipulation.

367. *First.* The sand is spread in a rectangular layer of two inches in thickness.

Mix sand and cement together, dry.

368. *Second.* The dry cement is spread equally all over the sand.

369. *Third.* The men place themselves, shovel in hand, two on each side of the rectangle, at the angles, facing inwards. Furrows of the width of a shovel, are then turned outwards along the ends of the rectangle, until the whole bed is turned. The two men on one side thus find themselves together, and opposite the two on the other side, having, of course, left a vacant space transversely through the middle, of double the width of a shovel. They then move back to their original positions in turning furrows as before, when the bed occupies the same space that it did previous to the first turning. The turning is executed by successively thrusting the shovel under the material, and turning it over about one angle as a pivot. Each shovel thus moves to the middle of the bed, where it is met by the one opposite, when each man moves back to the side in dragging the edge of his shovel over the furrow he has just turned.

Incorporating the ingredients.

370. *Fourth.* A basin is formed, by drawing all the material to the outer edge of the bed.

Adding the water.

371. *Fifth.* The water is poured into the basin thus formed.

372. *Sixth.* The material is thrown back upon the water, absorbing it, when the bed occupies the same space that it did at the beginning.

373. *Seventh.* The bed is turned twice, by the process described above. If required for mason's use, the mortar is then heaped up, to be carried when and where required. If for concrete, (the mortar occupying the rectangular space, as at first).

Concrete.

374. *Eighth.* The broken stones are spread equally over the bed.

375. *Ninth.* A bucket of water, more or less, (depending upon the quantity of stones, their absorbing power, and the temperature of the air), is sprinkled over the bed.

376. *Tenth.* The bed is turned once as before, and then heaped up for use. The act of heaping up, which is done with care, has the effect of a second turning.

Incorporating the broken stones.

377. The time consumed in making a batch of mortar is a little less than twenty minutes; in incorporating the broken stones, ten minutes more.

378. When the mortar is required in very small quantities, to avoid deterioration, instead of proceeding to the fourth step of the manipulation, the mixture of cement and sand is heaped up, and the water added and paste formed with the hoe, in such quantities as are required.

379. *Composition of Mortar.*—The mortar at Forts Richmond and Tompkins, whether required for stone masonry or for concrete, contained *one* cask* (or 308 pounds net) of hydraulic-cement powder, which produced 3.70 to 3.75 cubic feet of stiff paste; and *three* casks, or about twelve cubic feet of loose sand, equal to 2.44 casks (about 9.75 cubic feet), well compacted. These ingredients being incorporated, produced 11.75 cubic feet of rather thin mortar.

Composition of the mortar.

380. *Composition of Mortar used at Fort Warren.*—The mill-made mortar for the *stone* masonry at Fort Warren was composed of lime, hydraulic cement, and sand, in the following proportions, viz.:

Composition of the Fort Warren mortar.

One cask dry cement (325 lbs. net), producing 3.75 to 3.85 cub. ft. of stiff paste.
One-half cask of Rockland lime (120 lbs. net), producing four cub. ft. of stiff paste.
Nineteen and one-fourth cubic feet of loose sand, equal to fourteen and a half cubic feet well compacted.

* The average net weight of a barrel of cement is 308 pounds.

These ingredients being well mixed, make eighteen and a half cubic feet of good mortar.

For mortar for *brick* masonry, the same quantities of lime and cement received but fifteen and three-quarters cubic feet of loose sand, equal to twelve cubic feet well compacted, giving sixteen cubic feet of good mortar.

Estimating the cost of the lime at .70 cents per cask of 240 lbs. net, the cement at $1.62½ per cask of 325 lbs. net, and the sand at .50 cents per gross ton, labor at .91 cents, and horses .40 cents per day of ten hours, and we have the following analysis of the cost of the two kinds of mortar used at Fort Warren:

MORTAR FOR STONE MASONRY.

Mortar for stone masonry.	1 cask cement, 325 lbs. net=385 cubic feet of paste, at $1.62½	$1.630
	½ cask lime=four cubic feet of paste, at 70c.	.350
	14.67 cubic feet sand, at 50c. per ton	.496
	Labor of men, at 91c. per day	.245
	Labor of horse, at 40c. per day	.028
	Total cost of a batch of 18½ cubic feet of mortar, corresponding to one cask of cement	$2.75
	Cost of 1 cubic foot of mortar	.14½
	" 1 " yard "	3.93

MORTAR FOR BRICK MASONRY.

Mortar for brick masonry.	1 cask cement, at $1.63	$1.63
	½ cask lime, at 70c.	.35
	12 cubic feet sand, 50c. per ton	.409
	Labor of men, 91c. per day	.208
	" horse, 40c. per day	.024
	Total cost of a batch of mortar of 16 cubic feet, corresponding to one cask of cement	2.621
	Cost of 1 cubic foot of mortar	.16⅓
	" 1 " yard "	4.40

381. Some engineers object to the use, in works of importance, of mortar containing so large a proportion of sand as that adopted at Forts Richmond and Warren; others again very seldom add lime to their cement mortars. Touching this last-mentioned point, recent experiments show, with a uniformity quite satisfactory, that most American cements will sustain, without

any great loss of strength, a dose of lime paste equal to that of the cement paste; while a dose equal to ½ to ¾ the volume of cement paste may safely be added to any energetic Rosendale cement, without producing deterioration in the quality of the mortar, to a degree requiring any serious consideration. Neither is the hydraulic activity of the mortars so far impaired by this limited addition of lime paste, as to render them unsuitable for concrete, under water or other submarine masonry; while, for constructions not subject to immediate submersion, or the action of the returning tide, it is to be preferred on many accounts. By the use of lime, we secure the double advantages of a rather slow mortar—one that is in no danger of setting before it reaches the mason's hand—and a cheap mortar. We also avoid the principal serious objection to the use of a quick-setting mortar, due to careless and tardy attendance on the masons, and consequently the constant breaking up of the incipient set on the mortar-board, whereby cements are degraded in energy to a level with ordinary hydraulic limes.

Proportion of lime that may be added to cement mortars.

The advantages of the lime.

382. If the lime paste had been replaced by cement paste in the Fort Warren mortars, the mortar for stone masonry would have cost $5.96 instead of $3.93 per cubic yard, and that for brick masonry $6.69 instead of $4.40; while if lime paste had been used exclusively, the cost would have been only $2.53 for the first, and $2.72 for the second.

Comparison of cement and of lime mortars.

383. In extensive operations it is well to have a mortar-box and cart for transporting the mortar from the mill to the work. The box should be made of stout planks, and be about 5½ feet long, 3½ feet wide, and 9 to 10 inches deep, and so arranged that it can be readily slung up underneath the cart, by means of a windlass. Figs. 37, 38, and 39 represent the cart and box used with entire satisfaction at Fort Warren and elsewhere.

Mortar-box and cart.

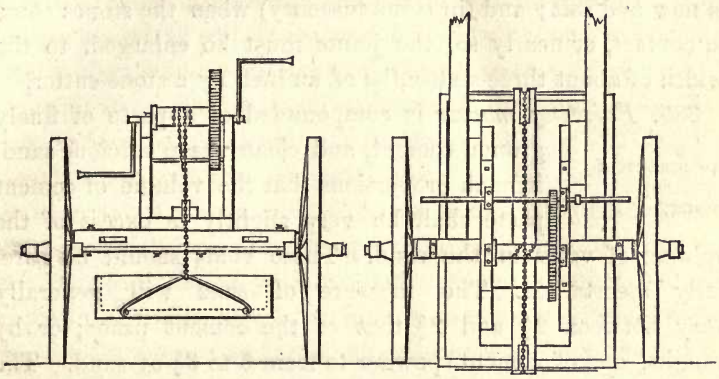


Fig. 37. Fig. 38.

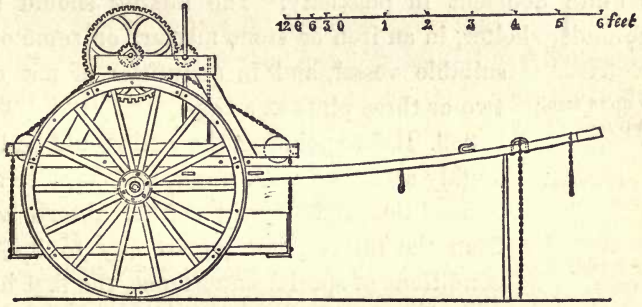


Fig. 39.

POINTING MORTAR.

384. In laying up masonry of any character, whether with common or hydraulic mortar, the exposed edges of the joints will naturally be deficient in density and hardness, and, therefore, unable to withstand the destructive action of the elements; particularly variations in temperature, producing extremes of heat and cold. It is therefore customary, to fill the joints as compactly as possible, to the depth of about half an inch, with mortar prepared especially for the purpose. This operation is called "*pointing*," and the mortar, "*pointing mortar*." The cleaning out of the joints to the requisite depth should take place while the mortar

Why "pointing" is necessary.

is new and soft; and (in stone masonry) when the stones come in contact, or nearly so, the joints must be enlarged, to the width of about three-sixteenths of an inch by a stone-cutter.

Composition of "pointing mortar."

385. *Pointing mortar* is compounded of a paste of finely ground cement, and clean sharp silicious sand, in such proportions that the volume of cement paste shall be very slightly in excess of the volume of voids in the sand. These voids should be carefully ascertained. The measure of sand will generally vary between $2\frac{1}{2}$ and $2\frac{3}{4}$ that of the cement paste; or by weight, one of cement powder to from 3 to $3\frac{1}{3}$ of sand. The mortar, when ready for use, should appear rather incoherent and quite deficient in plasticity. The mixing should take place under shelter, in an iron or stone mortar, or some other suitable vessel, and in quantities of not over two or three pints at a time.

Made up in small quantities.

The wall should be moistened *before* pointing, and not allowed to dry rapidly afterwards.

386. Before pointing, the wall should be thoroughly saturated with water, and kept in such a condition, that it will neither absorb water from the mortar, nor impart any to it,—two conditions of special importance, the first being paramount.

Walls should not be allowed to dry too rapidly after pointing, but should be kept moist for several days, or better still, for two or three weeks. Pointing in hot weather should therefore be avoided, if possible; or else some temporary shelter from the direct action of the sun's rays should be provided.

Tools required in pointing.

387. For pointing masonry in courses, the tools required besides an ordinary mason's trowel are, a straight-edge, about six feet long; a caulking iron, measuring three inches by one-eighth of an inch on the edge; a hammer, and some conveniently shaped iron or steel instrument for polishing the surface of the joint in the last stage of the operation. The mortar is put in the joint with the trowel, the straight-edge being placed

against the wall, just below the joint, as an auxiliary. The joint is then well caulked with the caulking iron, by repeated blows of the hammer, until a film of water shows itself on the surface of the mortar; after which, mortar is again put in, and the caulking repeated. In using the straight-edge, two men, one at each end, can conveniently work. The operation is continued until the joint is entirely full. The mason then rubs and polishes the joint, under as great a pressure as he can exert, and finishes off by using the straight-edge and trowel point, to remove any mortar spread out upon the stones on either side, make the pointing straight, and give the appearance of exact equality in the thickness of the joints. Manner of using them.

388. In pointing rubble masonry, the same general direc tions are applicable, but the use of the straight-edge has to be dispensed with.

INTERIOR PLASTERING.

389. The signification of the term plastering will be limited to the covering of interior walls and ceilings. Exterior plastering will be denominated "stucco," although the technical signification of the latter term is much more limited, and refers to a mixture of white lime, putty, and white sand or powdered marble, used for inside finishing, and to a coating made with this compound. Interior plastering. Stucco.

390. Among the implements used by the plasterer, the principal ones are the hawk, the plastering or laying-on trowel, the float, and straight-edges of various lengths. Tools.

391. The hawk, used by the plasterer for conveying and holding the mortar, while he applies it with the trowel, is a piece of board about eleven inches square, and is held by a handle fixed beneath in the centre of, and at right angles to the board. Hawk.

Trowel.

392. The trowel for laying the mortar consists of a steel blade about 3 inches by 9 inches, rounded slightly at the front end, and a little convex on the face, with a wooden handle on the back parallel to the blade.

Hand-float.

393. The hand-float is of wood, similar in shape to the trowel, and is used to rub down the finished work and make it solid, smooth, and even. A cork float is used upon surfaces that are to receive a high degree of polish with the trowel.

Mortars used for plastering.

394. The mortars used for inside plastering exclusively, are "coarse stuff," "fine stuff," "gauge stuff," or hard-finish, and "stucco."

Coarse stuff.

395. *Coarse stuff* is nothing more than common lime mortar, suitable for brick masonry, to which has been added a quantity of well-switched bullock's hair, to act as a kind of bond. The following proportion is a good one:

1 cask lime	= 8 cubic feet of paste.
Sand	16 to 18 cubic feet.
Hair	1½ do. do.

Its uses.

396. When ample time for hardening cannot conveniently be allowed, it will be advantageous to replace 12 to 15 per cent. of the lime paste in the coarse stuff, by an equal volume of the paste of hydraulic cement or plaster of Paris. Coarse stuff forms the principal part of all inside plastering. For the second coat, in three-coat work, the quantity of hair given above may be slightly diminished.

Fine stuff.

397. *Fine stuff* is made of pure lump-lime slaked to paste with a moderate quantity of water, and afterwards diluted with water to the consistency of cream, and then placed where it can stiffen by evaporation to the proper condition for working.

Its uses.

398. Fine stuff is used for the finishing coat, but never without the addition of sand or plaster of Paris, except for what is termed a "slipped coat."

Even for slipped work, a little fine sand is sometimes added, to make the paste work more freely.

399. *Gauge stuff*, or *hard-finish*, is composed of fine stuff (lime putty) and plaster of Paris, in proportions regulated by the degree of rapidity required in hardening. As it sets rapidly, it is always prepared in small quantities at a time, not more, for instance, than can be used up in half an hour. It is used for the finishing coat of walls, and for cornices, mouldings, and other kinds of ornamentation. For finishing, the proportions are three to four volumes of lime putty to one volume of plaster of Paris, and for cornices, &c., about equal volumes of each.

Guage stuff, or hard-finish.

400. *Stucco* is composed of lime putty and white sand, with a preponderance of the latter. The usual proportions are three to four volumes of sand for one volume of putty.

Stucco.

Stucco is only used for the finishing coat.

Its uses.

401. According to the English plasterer's nomenclature, applying the first coat, which is always done with coarse stuff, is technically termed "rendering," if on masonry; "laying," if on laths in one or two coat work; and "pricking up," if on laths in three-coat work. In the United States, the first coat of three-coat work on laths is called the "scratch" coat, instead of the "pricked up" coat. The other terms, with the English signification, are retained here.

Plasterer's nomenclature.

402. In "rendering," the joints of the masonry should be raked out to the depth of half an inch, the surface freed of dust, and the walls moistened. Old masonry, if smoky or greasy, should also be scraped out and roughened.

Precautions in rendering.

403. *One-coat work.*—Plastering in one coat without finish, either on masonry or laths, that is, either *rendered* or *laid*, though the most inferior kind of covering for walls, is frequently used for attics and kitchens in

One-coat work.

Is for cheap work.

cheap houses, and for cellars, vaults, and places of like character. The coarse stuff is applied in the same manner as the first coat in two-coat work, described below. A light hand-floating is of great advantage to this kind of work.

404. *Two-coat work.*—Plastering in two coats is done either in a "*laying coat* and *set*," or in a "*screed coat* and *set*." The *screed* coat is also called the *floated* coat. It is more commonly applied as the second coat in three-coat work. *Laying* the first coat in two-coat work, is resorted to in common work instead of *screeding*, when the finished surface is not required to be exactly even, to a straight-edge. It is performed in a pretty thick coat,—say half an inch,—more care being taken to secure a smooth and even surface than in the *scratch* coat for three-coat work, because, in the latter case, all the irregularities are removed by the *screed* coat which follows. In both the laying and the scratch coats, the coarse stuff should be well tempered, and of such moderate consistency, that when pressed with force against the laths, it will penetrate between them, and bend down over them on the inside, so as to form a good key. A common fault in lathing, is to place the laths so close together, as to render it impossible to obtain a strong key.

Two-coat work.

Coarse stuff to be well tempered.

Common fault in lathing.

405. Except for very common work, the laying coat should be *hand-floated*, to give it density and solidity. This is done by using the float in the right hand, and a hair-brush holding water, in the left; both instruments passed quickly over the wall at the same time, the brush preceding the float, and wetting the surface to the required degree. The firmness and tenacity of plastering is very considerably increased, by hand-floating, and at a moderate expense.

Hand-floating.

406. Hand-floating must take place while the mortar is green, when it is intended as a preparation for the setting coat.

Must take place while the mortar is green.

407. In two-coat work, performed in a *screed coat* and *set*, the first coat must be put on in "screeds" and "filling out." The screeds are strips of mortar six to eight inches in width, and of the required thickness of the first coat, applied at the angles of the room, and parallelly, at intervals of three to five feet, all over the surface to be covered. These screeds are carefully worked on, so as to be accurately in the same plane, by the frequent application of the straight-edge in all possible directions. When these have become sufficiently hard to resist the pressure of the straight-edge, the "filling out" of the interspaces flush with the surface of the screeds takes place, so as to produce a continuous, straight, and even surface. The surface should then be hand-floated as described above.

Screeding described.

The screed coat to be hand-floated.

408. After the first coat, whether it be a laying coat or a screed coat, has become partially dry, so as to resist the pressure of the trowel, it is ready for the setting, or finishing coat. This may be either in *slipped work*, *stucco*, *bastard stucco*, *or hard-finish*. In all cases, the surface to receive it must be roughed up with a birch or hickory broom, or some suitable instrument, and if too dry, must be moistened.

Finishing.

409. A *slipped* coat is merely a smoothing off of a brown coat (coarse stuff), with the smallest quantity of lime putty that will answer to secure a comparatively even surface. It is seldom sufficient to cover the browning up entirely.

Slipped coat finishing.

410. A small quantity of white sand, seldom exceeding three per cent., is sometimes added to the putty to make it work more freely. The trowel alone is used for this kind of finish. It answers very well for surfaces that are to be finished in distemper, or with paper-hangings of common or medium quality.

Sand sometimes used in the slipped coat, when slipped work is resorted to.

411. Finishing or setting in stucco is suitable for a screed

Stucco finishing.

coat, but is never applied to laying or to inferior work, on account of the extra labor which it requires. The stucco is applied with the trowel, to the thickness of about one-eighth of an inch, keeping in view the fact that the straight surface gained by screeding can only be preserved by applying the set in a coat of uniform thickness. The stucco is well hand-floated, the water-brush being used freely while so doing. After the wooden float has been used, the surface is again floated in the same manner with the cork float, which being soft, leaves the surface in good condition for polishing. The polishing is performed with the trowel and brush; this operation, however, is omitted, when the stucco is intended to present a rough appearance for painting, or for any style of ornamentation in distemper.

Applied with trowel.

To be hand-floated.

Polishing.

412. *Bastard stucco*, like stucco, is also used as a setting coat on screed work. It is done in stucco mortar, containing a smaller quantity of sand than is suitable for genuine stucco, and sometimes a little hair. There is no hand-floating in this kind of work, and the trowelling is done with less labor than that conferred on trowelled stucco, as above described. Bastard stucco is superior to slipped work as a preparation for papering.

Bastard stucco

Done in stucco mortar, with a diminished dose of sand.

Is superior to slipped work.

413. *Hard-finish* is applied with the trowel, to the depth of about one-eighth of an inch. It may be polished with the water-brush and trowel, but the hand-float cannot be used upon it. Hard-finished walls, though frequently painted, are by no means so well adapted to that kind of covering as stuccoed walls. They may, however, be well finished in distemper; a suitable composition for this purpose consists of ten pounds of Paris white and one pound of glue, colored as required. The advantage of hard-finish over stucco consists in its requiring less

Hard-finish.

Cannot be hand-floated.

May be well finished in distemper.

labor to apply it. It is extensively practised in the United States.

414. *Three-coat work.*—The *first* and *second* coat are termed respectively the *scratch* coat and *brown* coat, and the third is either *hard-finish*, or *stucco*. Three-coat work.

415. The *scratch* coat, or first coat, is applied in the same manner as *laying*, with this exception, that, as it is simply intended to form a good foundation for the *screeding* which follows, its thickness need not exceed one-quarter to three-eighths of an inch. When completed, and partially dry, though still quite soft, the mortar is *scratched* over nearly to its entire depth, with a pointed stick, in two systems of parallel scorings at right angles to each other, running diagonally between the extreme limits of the surface covered. These scorings are about two inches apart, and assist the adhesion of the coat which follows. Scratch coat.

416. The second coat is applied in "screeds" and "filling out," in all respects as described in *screed-coat* and *set* work.

417. The finishing or setting is also applied as before described.

418. Table XV. gives an estimate of labor and materials for 100 yards of lath and plaster work:

TABLE XV.

Materials.	Three coats Hard-finished work.		Two coats Slipped work.	
Rockland lime	4 casks	$4.00	3½ casks	$3.33
Lump lime for fine stuff	⅔ "	.85		
Plaster of Paris	½ "	.70		
Laths	2,000	4.00	2,000	4.00
Hair	4 bushels	.80	3 bushels	.60
Common sand	7 loads	2.00	6 loads	1.80
White "	2½ bushels	.25		
Nails	13 lbs.	.90	13 lbs.	.90
Mason's labor	4 days	7.00	3½ days	6.12
Laborer	3 "	3.00	2 "	2.00
Cartage		2.00		1.20
Cost of 100 yards		$25.50		$19.95

EXTERIOR PLASTERING, OR "STUCCO."

419. Mortars composed of the paste of common lime and sand, either with or without the addition of plaster of Paris, are unsuitable for covering surfaces exposed to the direct action of the elements.

Common mortars unfit for outside work.

420. Lime, however, forms the basis of many excellent outside stuccos, and, by proper treatment, may be rendered very durable.

421. If the water for mixing the mortar contains coarse sugar or molasses in solution, the effect on the solidification of the outer surface of the stucco is very beneficial. This method is practised by the natives of India, as reported by Captain Smith in his translation of Vicat. The proportions for the sweetened water are about one pound of sugar to eight gallons of water, except for the outer or hand-floated coat, in which one pound of sugar should be mixed with two gallons of water.

Use of sugar-water.

422. Powdered slaked lime and smith's forge scales mixed up with bullock's blood in suitable proportions, make a durable and moderately hydraulic mortar, which adheres well to masonry previously coated over with boiled oil. It is used for outside stucco.

Smith's forge scales.

423. The custom in the United States is to use hydraulic cement and clean sand, mixed up with a sufficiency of water to produce the ordinary consistency of mortar for plastering, and in such quantities that all may be used up before the batch begins to set. The proportions are one volume of stiff cement paste to 1.66 volumes of damp, compact sand; or, if measured dry, one volume of cement powder to two volumes of loose, dry sand.

Hydraulic cement stucco.

424. When masonry, either of brick or stone, is to be stuccoed, the joints should be raked out to the depth of half an inch; the surface cleansed of dirt and

Applying the same.

dust, and then thoroughly wetted, (with a hose, if possible,) so that the mortar will not be too rapidly deprived of its moisture by absorption, and its strength and density thereby impaired. If the surface is greasy, it should be scored with an axe.

425. The mortar is applied in two coats laid on in one operation. That for the first coat should be somewhat thinner than that for the second, in order that it may be pressed into thorough contact with the wall, and enter and fill up all the joints and other openings. The second coat is applied upon the first, while the latter is yet soft, so that the same workman finishes off as he goes along, never covering more than two or three superficial feet at one time. The two coats thus laid should form one compact coat, of about one-half inch in thickness. The finished stucco should be kept shaded from the direct rays of the sun for some days, and moistened from time to time.

First coat of rather thin mortar.

Second coat.

Finished stucco to be protected from sun, and kept moist.

426. As a modification of the above process, the first coat is sometimes omitted, or rather replaced by a wash of thick cream of pure cement, applied with a stiff brush, from time to time, just before the mortar is put on. If the brush-work is faithfully done, and not allowed to dry before the surface receives the stucco, an intimate contact and firm adhesion are sure to result.

Modification of above process.

427. A necessary precaution in this kind of work is to secure the services of a faithful workman, one who will not spare his strength, or lay any of the mortar on too loosely, or on too dry a surface; otherwise, there will be portions without adhesion, that will be thrown off on the first occurrence of frost.

Precaution.

428. After the stucco has been on for a few days, the whole surface should be carefully sounded with a small iron instrument like a

Examination of exterior stucco.

tack-hammer, when all places destitute of adhesion will be readily detected by their hollow sound. From these, the stucco should be carefully removed, the surface roughened and wetted, and new mortar applied.

Management of color.

429. Many of the best cements of the United States are of too dark a color to furnish an agreeable shade for the exterior of dwelling houses. A very simple remedy for this is to use light colored or white sand, in whole or in part. When this is not practicable, lime paste may be added, without material injury, until its volume equals that of the cement paste. Lively tints may be obtained by a judicious use of the several ochres, singly or combined.

Disintegration of mortars in the air.

430. The principal causes of the gradual deterioration and decay of mortars left in the open air are:

1st cause.

1st. Ordinary changes of temperature, producing expansions and contractions, which, being unequal in the several materials ordinarily used in masonry, tend to cause a separation of the mortar from the more solid parts.

2d cause.

2d. Alternations of freezing and thawing, by which exfoliations and disintegrations are produced.

General fact.

431. As a general fact, within certain limits, solid bodies resist the action of frost in proportion to their density, or inversely as their capacity for imbibing water; but this rule is not capable of strict application, and it is quite possible for one mortar to be a better proof against frost than another less porous in its character. Moreover, of two mortars of equal density, one may be materially impaired in tenacity and hardness by the action of frost, while the other exhibits few, if any, evidences of its effects.

Some mortars resist frost better than others that are less porous.

432. Immersed in water, more especially sea-water, mortars

are subjected to the solvent action of the salts —principally the sulphates of magnesia and soda,—and certain gases contained in the water. Between tides, are witnessed the effects of a combination of the foregoing causes, modified and sometimes augmented by the circumstance, that the protecting coat of marine animals and shells, to which many submarine constructions in a measure owe their stability, is seldom found at all, and at best, but very imperfectly, in positions not subject to constant submersion. It is hence, not an uncommon thing to see the mortar of that portion of a structure between high and low water, in a more advanced stage of decay than that above or below.

Action of certain salts in sea-water.

Exposure between the tides.

433. The effects of frost on mortar may be ascertained by subjecting it to repeated action of artificial frigorific mixtures. To do this, the mortar should be four or five months old, and in the form of a prism of suitable size, say $2'' \times 2'' \times 8''$. Ascertain the strength before the freezing trial, by breaking the prism, near one end, on supports four inches apart. Then saturate the largest piece with water, put it in a thin, water-tight bag of India-rubber or gutta-percha cloth, and immerse it in one of the frigorific mixtures given below, where it should be kept until the temperature of the mixture rises above the freezing point. The sample should then be laid in some warm, dry place, until it is completely thawed out. After eight or ten repetitions of this process, the strength of the mortar should be ascertained as in the first instance, when the effect of frost will become known.

To ascertain the effects of frost.

TABLE XVI.

FRIGORIFIC MIXTURES.

Mixtures.	Parts.	Thermometer sinks.	Mixtures.	Parts.	Thermometer sinks.
Snow or pounded ice	2	From any temperature to—5° F.	Snow or pounded ice..	5	From any temperature to—12° F.
Common salt.....	1		Common salt.....	2	
			Sal ammonia.....	1	
Snow or pounded ice	24	From any temperature to—18° F.	Snow or pounded ice..	12	From any temperature to—25° F.
Common salt.....	10		Common salt	5	
Sal ammonia.....	5		Nitrate of ammonia ...	5	
Nitrate of potash ...	5				

434. The process of a French chemist, M. Brard, for estimating the probable effects of frost on stone, given in the "Annales de Chimie et de Physique," volume 38, is equally applicable to mortar. It may be stated very briefly as follows, viz.: Prepare a cold saturated solution of sulphate of soda, then bring it to the boiling point, and suspend in it, by a string, for thirty minutes, the sample under trial. Then pour the liquid, free of sediment, into a flat vessel, and suspend the stone over it in a cellar. When efflorescences appear on the specimen, it must be dipped in the solution, say two or three times a day for about a week; at the end of which time the quantity of earthy sediment in the vessel, collected on a filter and weighed, will indicate the effect to be expected from frost on the same sample. The sample under trial might also be of such a form, that its strength could be tested before and after subjection to the above process. M. Brard, however, makes no recommendation of the kind, and it is perhaps unadvisable when operating upon stone.

M. Brard's process.

435. The subject of the action of sea-water on mortars, particularly the pozzuolana mortars used in the Mediterranean Sea, and the conflict of opinion thereon among European engineers, has been referred to in brief terms in Chapter IV. To estimate by preliminary experiments the probable effects of sea-water on mortars, in any

Effect of the sea-water on mortars.

given case, is a difficult thing: in fact, there are so many elements of uncertainty involved in it, that many engineers deem it impossible. Nevertheless, M. Vicat proposed in 1857 "a new mode of trying sea-mortars in the laboratory," which, as it emanates from high authority, is entitled to notice. The mortar to be tried, when mixed up, is pressed, while green, into an earthen vessel. The vessel should be full and should be kept closely covered, to prevent contact with the air. At the expiration of one month break the vessel, so as to free the mortar, and then immerse the latter in water containing four or five thousandths of anhydrous sulphate of magnesia. Reaction takes place,—the water dissolves the sulphate of lime formed, its presence being detected by oxalate of ammonia, which yields a precipitate of oxalate of lime.

M. Vicat's new method of testing same.

Immerse the mortar in a solution of anhydrous sulphate of magnesia

436. The solution of sulphate of magnesia should be renewed until no more of this oxalate is formed, and even beyond that point, for greater certainty.

Renew the solution.

437. If the sample shows no external signs of decay after ten months, break it open and examine the fracture. If the interior is in a state of perfect preservation, treat some fragments, taken from the inside, by the same process applied to the original sample. If these fragments remain intact, for a given time, (*yet to be ascertained*) the mortar may be pronounced suitable for sea constructions. For cement mortars, twenty months' successful resistance to the solution of sulphate of magnesia is considered ample by M. Vicat. For mortars of pozzuolana or hydraulic lime, it is not considered entirely safe to assign a minimum of two years; while it is by no means impossible for a mortar that fails to stand this test to sustain immersion in the sea, from the fact that the protecting coat, before referred to, is formed on the exposed surface.

Examination of specimen.

438. M. Minard, Engineer des Ponts et Chaussées, (retired,) concludes a review of M. Vicat's work in the "Annales des Ponts et Chaussées" for 1858, as follows:

M. Minard's opinion.

"The only means of knowing the action of the sea on a new mortar is to immerse it in the sea, in the locality where it is to be used. Substituting chemical operations in laboratories for the sea itself, involves us in new disasters."

CHAPTER VII.

439. *Concrete or Beton.*—These terms, by no means originally synonymous, have become almost strictly so by usage. As generally understood in modern practice, they apply to any mixture of mortar (generally hydraulic), with coarse materials, such as gravel, pebbles, shells, or fragments of tile, brick, or stone. Two or more of these materials, or even all of them, may be used together. More strictly speaking, as originally accepted, the matrix or gang of *beton* possesses hydraulic energy, while that of *concrete* does not.

Definition of terms "concrete" and "beton."

440. As lime or cement paste is the cementing substance in mortar, so mortar itself occupies a similar relation to concrete or beton. Its proportion should be determined in accordance with the principle, that *the volume of the cementing substance should always be somewhat in excess of the volume of voids in the coarse materials to be united.* The excess is added as a precaution against imperfect manipulation.

Proportion of matrix to the coarse materials.

441. In England, some years ago, when concrete first came into extensive application, common or feebly hydraulic lime, such as the Blue Lias limestone yields, was generally used for the cementing substance. The quicklime, having been first reduced to a powder by mechanical means, was incorporated with the sand and coarse materials in the dry state. Water, in sufficient quantity to slake the lime, being then added, the concrete was

Concrete of quicklime.

rapidly mixed up with a pug-mill or with shovels, conveyed away in barrows or carts, and used while hot. It was employed extensively for foundations, or as a substratum in light and yielding soils. In order to secure the requisite degree of compression and density, it was customary to throw it into its position from a height, and sometimes to ram it afterwards. In mixing the materials for fat lime concrete as usually composed, there is a contraction of about $\frac{1}{8}$ in volume; this is succeeded by an expansion, when the setting takes place, of about $\frac{3}{8}$ of an inch for every foot in height, which does not entirely cease for a month or two afterwards.

Used while hot.

Its contraction and subsequent expansion.

442. Concrete of fat or feebly hydraulic lime has been extensively employed in Europe for making artificial blocks of any required form and dimensions, which, after attaining in the air a degree of hardness and strength sufficient to render the handling of them safe and practicable, are laid up in walls with mortar joints, like ashlar-work.

Extensively used in Europe.

443. Of late years, the practice of laying fat lime concrete hot has grown into disrepute among English architects and engineers. They now prefer that the lime should be thoroughly slaked, reduced to a pulp, and made into mortar with the sand before the coarse materials are added. This process is always followed in making beton. The advantages of it are, immunity from the danger of partial slaking before use, superior homogeneousness in the mass, and economy in the amount of lime required.

The practice of laying "hot" concrete getting into disrepute.

444. Neither the English method of making concrete to be used while hot, nor the practice of forming artificial blocks which must attain in the air a certain degree of resisting power before they can be placed in the work for which they are designed, have ever received any extensive application in the United States.

English methods little used in the United States.

445. Natural hydraulic cement, to which, under circumstances requiring only a moderate degree of energy and strength, paste of fat lime is sometimes added, in quantities seldom greatly exceeding that of the cement, is almost invariably used as the basis of the concrete mortar; and the concrete, when made, is at once deposited in its allotted place, and well rammed in horizontal layers of about 6 inches in thickness, until all the coarser fragments are driven below the general surface. The ramming should take place before the cement begins to set, and care should be taken to avoid the use of too much water in the manipulation. The mass, when ready for use, should appear quite incoherent, containing water, however, in such quantities, that a thorough and hard ramming will produce a thin film of free water upon the surface, under the rammer, without causing in the mass a gelatinous or quicksand motion.

Hydraulic cement extensively used in the United States.

General practice.

Precautions in ramming, and in the use of water

Concrete should be incoherent before ramming.

446. It will be found in practice that cements vary very considerably in their capacity for water, and that fresh ground cements require more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for solidifying water is great. A too rapid desiccation of the concrete might involve a loss of cohesive and adhesive strength, if insufficient water be used.

An excess better than a deficiency of water.

447. Concrete is admirably adapted to a variety of most important purposes, and is daily growing into more extensive use and application. For foundations in damp and yielding soils, and for subterranean and submarine masonry, under almost every combination of circumstances likely to occur in practice, it is superior to brick-work in strength, durability, and economy; and in some exceptional cases, is considered a reliable substitute for the best

Uses and advantages of concrete.

stone, while it is almost always preferable to the poorer varieties.

448. For submarine masonry, concrete possesses the advantage, that it may be laid without exhausting the water, (which under the most favorable circumstances, is an expensive operation,) and also without the aid of a diving-bell, or submarine armor. On account of its continuity and impermeability to water, it is well suited to the purposes of a substratum in soils infected with springs, for sewers and conduits, for basement and sustaining walls, for columns, piers, and abutments, for the hearting and backing of walls faced with bricks, rubble, and ashlar-work, for pavements in areas, basements, and cellars; for the walls and floors of cisterns, vaults, &c. Groined and vaulted arches, and even entire bridges, dwelling-houses, and factories, in single monolithic masses, with moulded ornamentation of no mean character, have been constructed of this material alone.

Advantages for submarine works.

449. The methods pursued in mixing mortar on the fortifications of Boston and New York harbors, and at Key West, Florida, have been described in brief and general terms in Chapter VI., paragraph 346 and following. The manner of incorporating the broken stone fragments, as practised on the works at New York, is also briefly alluded to in the 7th, 8th, 9th, and 10th steps in the method of manipulation, paragraphs 373, 374, and 375. When the coarse fragments vary very much in their sizes, and these have been separated by a screen, as may be the case with gravel and pebbles collected in the usual way, a more thorough incorporation may perhaps be secured by spreading them first on the platform with the smallest sizes at the bottom, and then distributing the mortar uniformly over the mass. This process was followed in Boston, and is thus described by Lieutenant Wright, in his work on mortars:

450. "The concrete was prepared by first spreading out the gravel on a platform of rough boards, in a layer from eight to

twelve inches thick, the smaller pebbles at the bottom and the larger on the top, and afterwards spreading the mortar over it as uniformly as possible. The materials were then mixed by four men, two with shovels and two with hoes, the former facing each other, and always working from the outside of the heap to the centre, then stepping back; and recommencing in the same way, and thus continuing the operation until the whole mass was turned. The men with hoes worked, each in conjunction with a shoveller, and were required to *rub well into the mortar*, each shovelful, as it was turned and spread, or rather scattered on the platform by a jerking motion. The heap was turned over a second time in the same manner, but in the opposite direction, and the ingredients were thus thoroughly incorporated, the surface of every pebble being well covered with mortar. *Two* turnings usually sufficed to make the mixture complete, and the resulting mass of concrete was then ready for transportation to the foundation.

Incorporating the coarse ingredients by hand.

"The success of the operation, however, depends entirely upon the proper management of the hoe and shovel, and though this may be easily learned by the laborer, yet he seldom acquires it without the *particular attention of the overseer.*"

451. In Europe, machinery is sometimes employed for incorporating the ingredients of concrete, when large quantities are required.

452. The concrete for the bridge over the River Theiss, Hungary, completed in the year 1857, was prepared with a machine extensively used in Germany at that time. It consists of a cylinder about four metres (13 feet) in length, and 1.25 metres (four feet) in diameter, open at both of its extremities and revolving fifteen to twenty times per minute around its axis, which is inclined to the horizon at an angle of six to eight degrees. The stone and mortar are thrown from the wheel-barrow into a hopper, which empties them into the upper end of the cylinder. The mixture

Machine used in Hungary for mixing concrete.

is produced by the rotation of the cylinder, from the lower end of which the concrete drops into either wheel-barrows or carts. The inner surface of the cylinder is smooth and coated with sheet-iron ; the proportion of the material is measured by regulating the number of wheel-barrow loads of mortar and of stone, as these are poured into the hopper. The incorporation of the ingredients is complete. The cylinder is kept in motion without cog-wheels or pulleys, simply by means of a leather strap which passes over its exterior surface ; the motive power was furnished by a locomotive, which worked a heavy mortar-mill at the same time.

This machine easily mixes from 80 to 100 cubic metres (105 to 130 cubic yards), in ten hours, and (when worked in connection with a mortar-mill) at a trifling expense. (See *Annales des Ponts et Chaussées*, Vol. XVII., 1859.)

453. Another machine for making concrete, the mortar having been previously mixed, is represented by Figures 40, 41, 42, 43, and 44, the latter being a top view. It is always used in a vertical position, and being comparatively light and portable, and worked altogether by hand, possesses the advantage that, for founding in dry positions, or where the water has been exhausted, it can be suspended with its lower end resting on the position to be occupied by the concrete, and one handling of the materials be thereby saved. As it is moved successively from one position to another, during the progress of the work, it is followed up by laborers who level off and ram the concrete already deposited by it. In using this machine, the mortar and coarse materials, after having been measured, are placed in the top compartment, *a*, Fig. 40. The levers, *bb*, Fig. 44, being then put in motion, the materials fall successively from one compartment to another, little by little, and finally reach the bottom thoroughly and completely mixed. As the top compartment becomes empty, the ingredients for another batch of concrete are placed in it.

Machine for mixing concrete worked by hand.

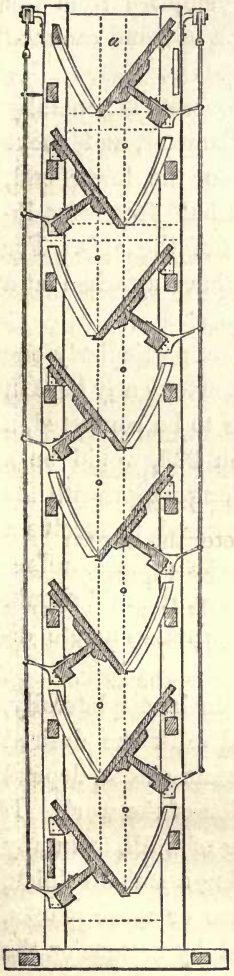


Fig. 40.

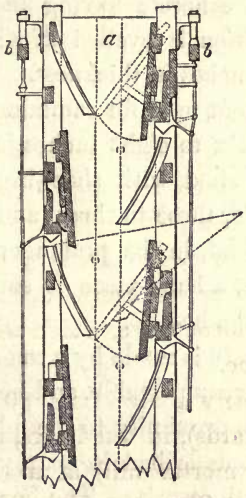


Fig. 41.

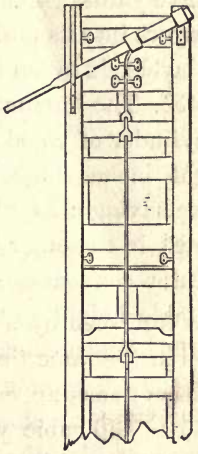


Fig. 42.

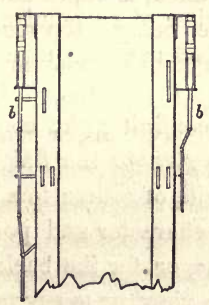


Fig. 43.

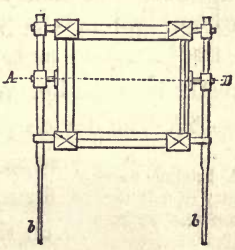
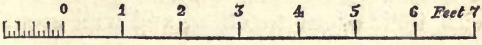


Fig. 44.



454. Wheel-barrows are generally used for conveying the concrete from the platform on which it is mixed, to its position in the work. The platform should be so arranged, if possible, that the distance to be passed over will not exceed twenty or twen-

Wheel-barrows for conveying concrete.

ty-five yards. The concrete having been emptied from the barrows into its position, is levelled off with a hoe, and rammed in layers six to ten inches in thickness.

455. The instrument used for ramming concrete is generally a cylinder of wood six to eight inches in diameter, and about eight inches high, shod with sheet-iron on the lower end, and having a handle, three to three and a half feet long, inserted in the other end, in the prolongation of the axis. For greater convenience, a hand-piece is sometimes attached at a suitable height on the handle.

Sling-cart for conveying concrete.

456. When concrete is made by a machine, particularly one not very portable, and not conveniently kept in close proximity to the place to be concreted, a sling-cart, like that described in paragraph 383, would be a valuable auxiliar to the work. The box slung underneath the cart, could be replaced by a platform arranged to receive a certain number of square boxes of convenient size for handling when filled. With a view to economize labor, the mill should be adjusted so as to discharge the manufactured concrete directly into the boxes.

A boxing necessary in making concrete walls.

457. The device for confining the concrete layers laterally, so as to give to the finished work the desired form, will, of course, to a certain extent, depend on the character and position of the work. If required for foundations, or for the backing of walls, or in any position not exposed to view, or not requiring a smooth finish, a rough, movable boxing, composed of two or more planks, with their edges together, and well secured by battens on the back, will suffice.

458. When it is required to give a smooth finish to the concrete wall, and when it is essential that the direction and position of the surfaces should be maintained with great accuracy, special attention should be directed to the boxing.

459. A device by Mr. E. E. Clarke, of New Haven, Conn., to be used in erecting concrete houses, has been pronounced

both convenient and satisfactory, while it apparently leaves nothing to be desired on the score of simplicity and economy. It consists essentially of a wood-

Improved movable boxing.

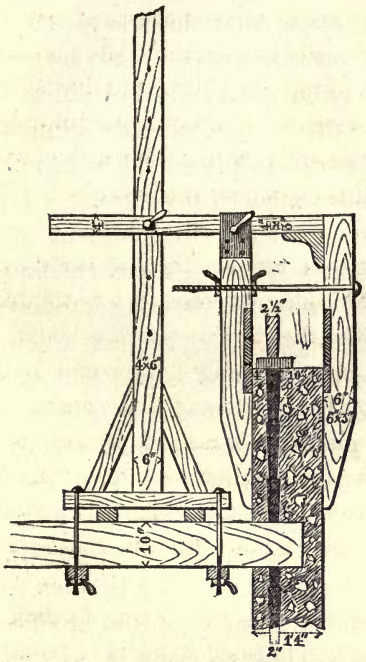


Fig. 45.

Fig. 46.

en clamp, the vertical parallel arms of which can readily be adjusted by means of traverse screws, to any required thickness of wall. These arms support the planking which determines the thickness of the wall, and are attached—one fixed, and the other movable—to a horizontal brace. When in use, the entire apparatus is kept in position by securing this brace to some fixed point of support. In carrying up the walls of a building, these points of support are provided on the inside, being vertical posts secured to the ground, in the first instance by braces, and afterward to the flooring joists of the upper stories.

Hollow walls.

Fig. 45 represents this apparatus in position for laying a hollow concrete wall, not intended to be furred on the inside. The hollow is secured by means of a movable plank, called a core, a trifle thinner on the lower than on the upper edge, so that it can be moved after the concrete is rammed around it. The ties between the inner and the outer walls may be common bricks, and these are placed under the "core" in each of its positions, as the building progresses. The "core" is notched on the lower edge, so as to fit down upon the ties flush with

their lower beds. Fig. 46 represents a side view of the core. The width of the hollow should be from two to three inches, the thickness of the inner wall from four to five inches, and that of the outer wall ten inches and upwards, as determined, to give the requisite strength. The hollow is sometimes placed in the centre of the wall, a practice which may be admissible in buildings not intended for residences. For these latter, when a thickness of five inches for the inner wall is exceeded, it should be furred for plastering, to prevent the condensation of moisture.

Movable boxing for pisé work.

460. The apparatus in common use on the continent of Europe and in some portions of South America, in constructing pisé work, would answer in forming walls of concrete, and would, besides, be less expensive, and perhaps more easy of adjustment and use than that shown in Fig. 45. It consists simply of a boxing of planks, kept in place by upright posts on the exterior, at suitable distances apart, say four or five feet. The lower ends of the posts are mortised and keyed into horizontal cross-pieces called futtocks, which reach entirely through the wall, and are withdrawn, and the holes filled up, after the box is filled with the pisé or concrete, and a new course is to be commenced. The upper ends of the posts may be kept in position by similar cross-pieces, but the more common practice is to confine them by lashings of rope or cord, tightened or loosened at pleasure by a stick used as a lever for twisting up the lashings. The wall may be made hollow by a core like that shown in Fig. 45.*

* Pisé work is formed of clay or earth rammed in layers. The best material is clay which contains small gravel, and is of such consistency, that it can be dug with a spade. The clay must first be thoroughly beaten up and passed through a screen to remove stones larger than a hazel-nut, and then moistened to a uniform consistency, so that, when moulded into form by hand, it will not fall to pieces under water. In forming walls, the pisé is rammed, like concrete, in layers from three to four inches in thickness, care being taken not to carry up the walls too rapidly, lest the lower portion be pressed out of shape, while damp and plastic, by the weight of the superincumbent mass. Except in very dry climates, the exterior of walls in pisé should be protected, by a coat of mortar, from the action of rain. The walls should be thoroughly dry, before being plastered.

Hollow concrete walls becoming extensively used.

461. Within the last ten years, the practice of building concrete houses with hollow walls, has received considerable attention, both in the United States and in Europe. In Sweden and Northern Germany, it is quite common. The facility with which the fire, smoke, and ventilating flues can be arranged in the wall, by using movable tubes during the progress of construction, the partial immunity from risks by fire, the security against the ravages of rats and other vermin, and the equality of inside temperature through sudden changes of weather, secured by this method of construction, judiciously followed, specially recommend it to the attention of American architects, particularly in those districts where the ingredients of concrete are plentiful and inexpensive, and timber or good building stone scarce. There are many recent examples of its successful application among us.

Its facilities and advantages.

Post foundations.

462. Fence or railing posts, of the minimum size consistent with the requisite degree of strength, may be firmly set and retained permanently in their upright position by surrounding them with concrete, or rather, by inserting them in a concrete foundation. The mortar for this purpose need not be very rich in cement, and in quantity, might barely exceed the volume of voids in the coarse materials. One foundation properly prepared would serve for an indefinite period of time, and the posts could be renewed as often as decay rendered it necessary. It is believed that by slightly tapering the lower end of the posts so as to render their removal simple and easy, and by lowering the entire foundation so as to place its upper surface below the reach of a plough, an excellent and inexpensive system of movable fences for farmers' use could be devised.

Use of cement for drain-pipes. Machine for making the pipes.

463. The quick-setting varieties of hydraulic cement have recently been quite extensively applied to drainage and sewerage purposes, in a mode at once new and peculiar. The mortar, composed

of 2 to 2½ measures of clean coarse sand to one measure of the cement powder, mixed with a small quantity of water, is moulded into pipe in sections of suitable length, say about three feet, and of any required diameter of bore up to 3½ or 4 feet. These sections, on being joined together with cement mortar, form a continuous water-tight tube. The junction may be secured by means of the ordinary "hub" joint, or by the "bevel" joint referred to below.

Fig. 48.

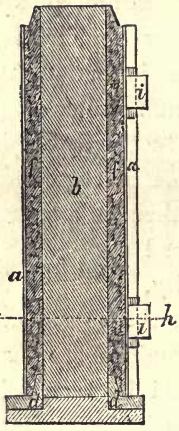


Fig. 49.

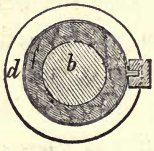


Fig. 50.

The essential parts of the machine for manufacturing these pipes are:

First, a sheet-iron cylindrical "case" in which the pipe is formed, its diameter being of course the same as the exterior diameter of the pipe. This cylinder is open longitudinally on one side, the two edges along the opening being turned out at right angles, thus forming flanges, by means of which the case can be firmly held together with wooden clamps.

Second, a solid cast-iron cylindrical "core" equal in diameter to the "bore" or interior diameter of the pipe. When this "core" is placed concentrically in the case, the cylindrical opening between the two, forms the mould for the pipe.

Third, a hollow cylindrical cast-iron rammer or "plunger" which fits over the core, so as to pass freely between the "core" and the "case." It is used for compressing the mortar. These several parts are represented separately by Figs. 48, 49, and 50, in which *a*, *a*, is the "case" clamped together at *i*, *i*; *b*, the "core," and *c*, the "plunger." They are combined together into a machine, worked by hand, which is represented by Fig. 51, in which A is the outside case and

B, the "core" not yet in position. This is suspended above the case. The plunger C is partially seen just below the hopper. The bottom of the mould is composed of a ring, *d*, *d*, Fig. 49, which gives the interior of one end of the section of pipe the bevel form of joint. A corresponding exterior bevel on the other end of the pipe is secured by making the lower end of the plunger of the required form (see Fig. 48). When the mould is filled the core is forced down into a pit below the machine, leaving the moulded pipe and the case containing it intact. These are then set on one side until the mortar has attained such condition of hardness that the case can be removed, which is easily done after the clamps are taken off.

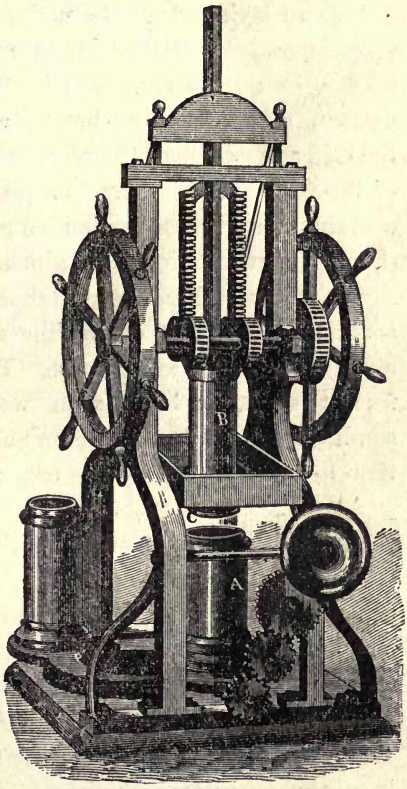


Fig. 51

The motion of the plunger, *c*, the pressure on the mortar, and the removal of the core, *b*, are all regulated by suitable machinery worked by hand, which need not be explained. Different sized pipes can be manufactured with the same machine by changing the essential parts, that is, the case, core, and plunger. In making large pipe, the plunger is dispensed with, and the requisite degree of density conferred by constantly ramming or "tamping" with crowbars. The bevel on the upper end is then formed by a ring (the reverse of that below) forci-

bly driven on when the case is full. By using 4 to 4½ parts of sand to one of cement, the pipe becomes porous and makes a good water filterer.*

Laying concrete under water.

464. In laying concrete under water, an essential requisite is that it should not fall from any height, but be deposited in the allotted place in compact masses, otherwise the cement would be washed away from the other ingredients, thereby seriously affecting the strength of the work. It is moreover proper that the concrete should contain a larger proportion of mortar, and that this latter should be rather richer in cement than would suffice under other circumstances. The most common method of depositing concrete is by means of a box of from nine to twelve cubic feet capacity, or by using a wooden pipe or conduit with its lower end resting on the position to be occupied by the concrete. A modification of this last mentioned device was used in laying the concrete foundation of Fort Carroll, Chesapeake Bay. It is called a *trémie* (Fig. 52), is made of boiler iron, and consists essentially of a truncated conical base, called the stock or hopper, and a vertical shaft in five sections. The lower section is permanently attached to the base, the other four are arranged with joints, and can be readily connected together. The trémie is suspended on a wooden frame or movable crane having four cast-iron wheels, running on a railway, by means of which the whole machine is moved

Trémie used at Fort Carroll, Chesapeake Bay.

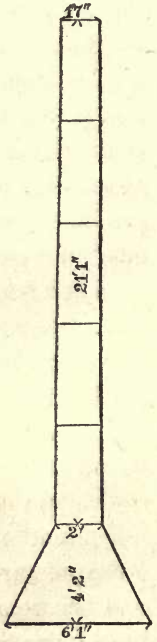


Fig. 52.

* Two manufactories of this pipe are in operation in the vicinity of New York, viz.: Pierce & Co. Sixty-first street, near Third Avenue; and Knight & Crawford, Jersey City. The prices of some of the principal sizes per lineal foot are as follows: 3 inch bore, 8 cents; 6 inch bore, 16 cents· 10 inch bore, 30 cents; 15 inch bore, 62 cents; 18 inch bore, 85 cents.

and regulated, as the work progresses. An upward and downward motion of the trémie, by which, in conjunction with the column of concrete in the shaft, the materials are compressed as they issue from the hopper, is secured and controlled by a powerful screw on the top of the frame. This screw is worked by two men.

465. The sections of the sea-wall at Fort Carroll filled with concrete by the trémie, were, in the clear, 8 feet by 8 feet horizontal section, and fourteen feet vertical height, equal to 896 cubic feet each. The time occupied in filling one of them was 9 hours 51 minutes (one day), the force employed consisting of 29 men including the overseer. Of this time 2 hours and 13 minutes were occupied in filling the submerged portion of the trémie stock, at the commencement of each day's operations. This was done by means of a cylindrical tub of such a size as to pass freely up and down within the trémie, and arranged to open at the bottom, like the concrete box described in paragraph 466, Fig. 53. The trémie stock was filled in this manner, until the concrete rose above the level of the water. After this, the concrete was thrown into the trémie with hods. In deep water, it is sometimes necessary to load the trémie. It is important that the upper surface of the column of concrete should be kept above the surface of the water. When, in the progress of the work, the base of the hopper reaches the water level, the trémie is dispensed with, and the concrete is rammed in the usual way.

Quantity of work done.

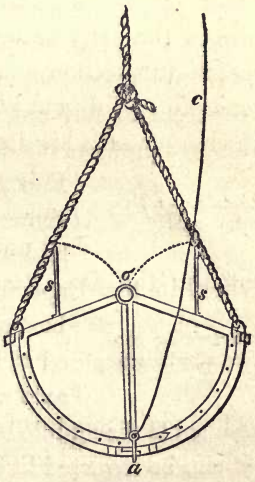


Fig. 53.

466. Fig. 53 represents an end view of the semi-cylindrical box for lowering concrete. It is in two parts, which join along the line o', a, and open around the hinge, o', so as to let the concrete through the bottom. A

pin at *a* keeps the two parts together until the box reaches the desired position, when it is withdrawn by means of the cord, *c*.

Box for lowering concrete in water. It opens at the bottom.

After the concrete is placed in the box, the top should be closed by sheet-iron covers, *s*, *s*, to prevent a rush of water over the mixture.

467. An improvement in the device for fastening the two parts of the box together, and one which, while it would render it impossible for careless or unfaithful workmen to open the box prematurely, and allow the cement to fall through the water, would also secure a considerable saving of labor, has been recently introduced by M. Sesquieres, Superintendent of Roads and Bridges in France. The box is of a prismatic form, of $\frac{33}{100}$ cubic yards capacity, and the bottom of it opens of its own accord, when it reaches and rests upon the soil or the concrete previously laid, and not before. This result is secured by a bar, attached longitudinally to the lower part of the box, and carrying a latch on each extremity, working into corresponding catches in such a way that an upward pressure on the bar, obtained in effect when the loaded box is lowered to its position, unfastens the bottom, allowing the mass of concrete to fall out when the box is raised again. M. Sesquieres prefaces his description of this box, in the Annales des Ponts et Chaussées, for 1854, by the following remarks: "Prior to the year 1841, 'beton' was laid under water in the hydraulic works executed in the Department of Tarnand Garoune by means of a box, of the form of a truncated pyramid, suspended at its extremity by a rope, winding around an axle worked with heaving bars; a rope is also attached to the middle of the bottom of the box, by means of which it can be inverted in order to empty it. This method is defective, as the box must be turned upside down to be emptied, which operation cannot be performed, unless the box is suspended at a

An improved fastening, which becomes detached, when the box reaches the bottom.

Remarks by M. Sesquieres.

Depositing concrete by inverting the box.

certain height above the bottom of the water; the consequence is that the beton becomes divided and washed off, so that, when it reaches the bottom, nothing is left of it but sand and pebbles. An unscrupulous contractor could even empty the box as soon as it had disappeared under the water," &c.

468. It may be remarked, however, that among French engineers, the relative advantages of the two methods of depositing concrete referred to (one by inverting the box, and the other by opening it at the bottom), have not yet been definitely settled, some preferring and practising one, and some the other. The size of these *caisses a immersion* is also a question still in controversy. M. Baudemoulin recommends the capacity of $\frac{1}{10}$ cubic metre. Experience seems to show that larger ones are better, as not favoring the formation of large quantities of *laitance*.* At Calais, boxes of $\frac{1}{10}$ cubic metre (3½ cubic feet) capacity were first used by M. Nehon; these were subsequently replaced by those of $\frac{1}{2}$ cubic metre (17½ cubic feet) capacity, which in their turn gave way to others, first of 1 and then of 2 cubic metres capacity, the constant aim being to lessen the volume of *laitance* formed. Preference was given to large sizes.

Relative advantages of the two methods of depositing concrete not settled by French engineers.

The size of boxes also a question of controversy.

469. It is considered injurious to ram concrete deposited under water. To obtain the necessary density, we must depend on the rake or some similar instrument gently used, to keep the layers approximately level, and on the weight of the superincumbent mass. Some eminent French engineers recommend the formation in a single mass or layer of concrete work under water, whether for foundations, platforms, or areas. The only advantage to be derived from this method, over the one of thin, continuous layers formed successively over extensive areas, ap-

Concrete not to be rammed under water.

Formation of submerged masses of concrete in single mass.

* See paragraph 474 on the subject of *laitance*.

pears to be the increased density of the portion first laid. This, before it begins to set, becomes well compressed by the weight subsequently added.

Use of sheet-piles.

470. In founding with concrete, it is usual to surround the place to be occupied by the work with sheet-piles, driven somewhat below the level of the base of the structure, and then to remove the soil to the requisite depth. In certain cases, when the soil is very firm, and the foundation has to reach to a small depth only, the piling need not be used; in others where these conditions do not obtain, it may be necessary to use piles of extra strength and length, and to support them against the pressure of the earth by braces at top. In order to prevent currents that might wash the concrete, holes should be left in the piling near the top, so that the water will remain at the same level within and without. In founding over springs, the action of which might drench the concrete, and wash out the cement, they might be stopped off by tarred canvas stretched over the area..

When sheet-piles can be dispensed with.

To prevent currents that might wash the concrete.

Precautions when founding over springs.

471. Concrete walls are frequently revetted or faced with stone. In fact, this is a common method at the present day of constructing sea-walls, and sustaining walls. The stone facing is generally in courses, composed of headers and stretchers alternately. The stretchers are so jointed on the end as to be a few inches longer on the back than on the front. The vertical joints on the headers, being formed at a corresponding angle with the face, while the tails of the headers, reaching entirely through the concrete backing, are left undressed, the wall becomes a firm and connected system of dovetailing. In constructing a wall of this kind, as soon as a course of facing stone is laid, the back to its entire thickness is levelled up with concrete, rammed in compact

Stone revetment of concrete walls.

Manner of constructing such a wall.

layers not exceeding one foot in depth, the surfaces of the stone having previously been freed from dust, moistened with water, and coated over with mortar, in order to insure the adhesion of the concrete.

472. Submarine walls of this description cannot be laid without exhausting the water within the area to be built upon, or using the diving-bell, or some other method of subaqueous construction.

473. For laying the sea-wall for the cover-face of Fort Taylor, located in 7 ft. of water, at mean low tide, Major Hunt, of the Corps of Engineers, devised a coffer-dam surrounded with a canvas case. This case consists of two parts firmly sewed together, viz.: the upright part, or case proper, and the flap. The case, when in use, stands vertically against the sheathing of the dam on the exterior, and its height should exceed somewhat the depth of the water where it rests. The flap lies out on the bottom, and has a width of 20 ft. all around the case, its object being to cut off infiltration through porous soils, when the coffer-dam is exhausted of water. The size of case at Fort Taylor is adapted to laying nearly 50 running feet of wall. In order to connect the section under construction with the part previously laid, a slit is left in the case, at one end.

Description of coffer-dam case devised by Maj. Hunt.

.474 When concrete is deposited in water, a pulpy, gelatinous fluid is washed from the cement, and rises to the surface. This causes the water to assume a milky hue, hence the term *laitance*, which French engineers apply to this substance. As it sets very imperfectly, and, with some varieties of cement, scarcely at all, its interposition between the layers of concrete, even in moderate quantities, will have a tendency to lessen, more or less sensibly, the continuity and strength of the mass. This pulp is produced more abundantly in sea-water than in fresh water. Its composition, as determined at the "Ecole des Ponts et Chaussées" in 1856, is given below.

Laitance.

Its injurious effects.

The sample was a thick jelly, of a dirty white color, possessing an alkaline reaction, and was produced in laying concrete in the Mediterranean Sea.

The analysis gave the following results:

Analysis of laitance from the Mediterranean Sea.

Insoluble in water	Silicious sand	2.888
	Silica	2.692
	Carbonic acid	2.570
	Alumina and traces of iron	.347
	Free caustic lime	.345
	Combined lime	3.998
	Magnesia	2.027
Total insoluble in water		14.867
Soluble in water		3.462
Water and loss		81.671
		100.000

475. The water of the Mediterranean contains nearly three pounds of magnesia per cubic yard, and the theory of this pulpy formation is that the immersed concrete gives up to the water free caustic lime in a finely divided state, which precipitates magnesia in a light and spongy form. This precipitate, interposing itself among particles of the mortar thrown into suspension by the motion of the liquids, produces the *laitance* so much complained of. The evil might be lessened by operating in a limited space where the sea-water could not be constantly renewed, or by using mortars possessing sufficient hydraulic activity to retain all their free caustic lime; but the usual means is to use several pumps for its removal. These should not be too large and powerful, on account of the injurious effects, on the mortar, of strong currents; even small ones should be operated with care. The proportion of the laitance is greatly diminished by using large immersing boxes, say of one to one and a half yards' capacity.

Theory of the formation of laitance.

How the evil might be lessened.

The laitance is usually removed by pumps.

476. *The nature and size of the coarse ingredients of con-*

crete will depend, of course, upon local circumstances. When a mixture of gravel and pebbles can be had, at a slight advance on the cost of collecting the same, it is generally used, on the score of economy, in preference to fragments of brick or stone. For a similar reason, oyster-shells are sometimes used, almost exclusively.

Nature and size of the coarse ingredients of concrete.

477. When concreting is carried on in connection with stone-cutting, and stone-masonry operations in general, the spalls, chips, and irregular fragments made by the cutters, can be converted into excellent concrete material at a moderate cost. This cost will, of course, vary somewhat with the kind of masonry and the quality of cutting, generally ranging, however, between fifty-five and seventy cents per cubic yard for labor only, allowing nothing for the refuse stock used.

Stone-cutters' chips.

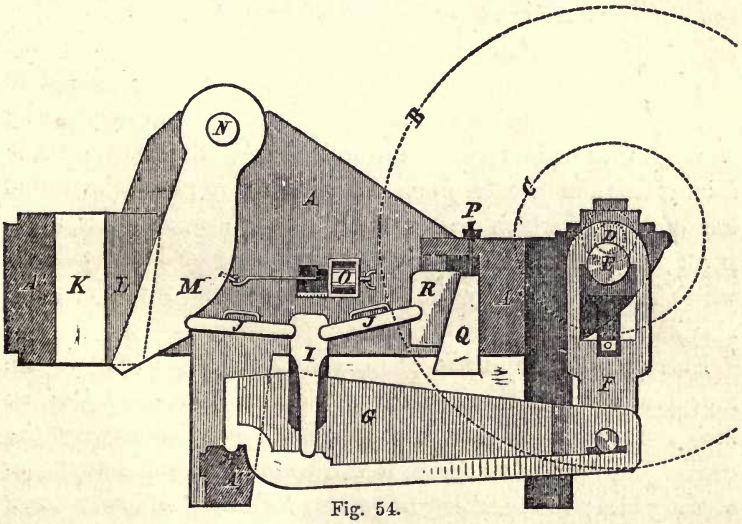


Fig. 54.

478. The preparation of concrete material by hand, from large masses of stone is considerably more expensive.

Breaking concrete by hand an expensive operation.

479. Figure 54 shows a longitudinal section of the essential

parts of a stone-breaking machine in use on the New York Central Park. A, A′, A″, A‴ is the frame of cast-iron in a single piece, which receives and supports the other parts. This frame consists of two parallel cheeks A connected together by the parts A′, A, ″A‴ (shaded with diagonal lines). The arc, B, represents a fly-wheel, of which there are two, one on each side of the frame, working on a shaft having its bearing on the frame. This shaft is formed into a *crank* E between the bearings, and carries a *pulley* C to receive a belt from a steam-engine or other driver. The fly-wheel, the section of fly-wheel shaft, the pulley, and the arc described by the centre of the crank in its revolution, are indicated by dotted circles. F is a *pitman* or rod which connects the crank with the *lever*, G. This lever has its fulcrum on the frame at H. A *vertical* piece I stands upon the lever against the top of which piece the *toggles* J J have their bearings, forming an elbow or toggle-joint. K is the *fixed jaw*, against which the stones are crushed. This is bedded in zinc against the end of the frame, and held back to its place by *cheeks* L that fit in recesses in the interior of the frame on each side. M is the *movable jaw*. This is supported by the round bar of iron N which passes freely through it, and forms the pivot upon which it vibrates. O is a spring of India rubber, which is compressed by the forward movement of the jaw, and aids its return.

Stone-breaking machine used in New York and elsewhere.

Description of same.

Every revolution of the crank causes the lower end of the movable jaw to advance towards the fixed jaw about $\frac{1}{4}$ of an inch and return. Hence, if a stone be dropped in between the convergent faces of the jaws, it will be broken by the next succeeding bite; the resulting fragments will then fall lower down and be broken again, and so on, until they are made small enough to pass out at the bottom. The distance between the jaws at the bottom limits the size of the fragments, and may be regulated at pleasure. A variation to the extent of $\frac{5}{8}$ of an inch

may be made by turning the screw-nut, P, which raises or lowers the *wedge*, Q, and moves the *toggle-block*, R, forward or back. Further variations may be made by substituting for the toggles, J J, or either of them, others that are longer or shorter; extra toggles of different lengths being furnished for this purpose.

Screening of the broken stone.

The broken stone passes from the machine into a revolving cylindrical screen standing at an inclination to the horizon, by means of which the material is separated in fine, medium size, and coarse stone. The meshes of this screen are small at the upper end, medium size at the middle, and large at the lower end. Fragments which pass entirely through the cylinder are returned to the machine and broken again.

480. The product of these machines per hour, in cubic yards of fragments, will vary considerably with the character of the stone broken. The proper speed is about 200 revolutions per minute.

481. The following table will give an idea of the capacity of these stone-breakers:

TABLE XVII.

Capacity of the machine.

Size of chamber at top.	Product per hour.	Power required.
10″ × 5″	3 cubic yards.	6 horses.
15″ × 5″	4½ " "	9 "
20″ × 7″	6 " "	12 "

482. Another excellence of the machine is the superior quality of its work. For concrete, a cubic yard of stone requires about 25 per cent. *less* of cement than stone broken by the hammer, for the reason that the former packs closer. The harder the stone, within certain limits, the greater the quantity the machine will break, as the product runs off more freely. The 15-inch machine weighs about 8,100 lbs; the 10-inch, 5,800.

Foundation concrete of Forts Richmond and Tompkins.

483. *Concrete foundations of Forts Richmond and Tompkins.*—The concrete for the foundations of Forts Richmond and Tompkins, New York harbor, was composed of hydraulic cement, sand, and granite fragments in the following proportions, viz:—

1 cask (308 lbs. net) of hydraulic cement which produced 3.65 to 3.70 cubic feet of stiff paste.

3 casks or 12 cubic feet of loose sand, equal to 9.75 cubic feet well compacted.

The sand and cement being well incorporated, yielded 11.75 cubic feet of rather thin mortar, to which were added 5 casks (20 cubic feet) of granite fragments, producing a batch of concrete measuring 21.75 cubic feet when rammed in the foundation.

Concrete for superstructures of Forts Richmond and Tompkins.

484. *Concrete for superstructures at Forts Richmond and Tompkins.*—For superstructures, the concrete contained 11.75 cubic feet of mortar as above, and 16 cubic feet of broken stone fragments.

485. The concrete foundation of Fort Tompkins contained about one-twelfth of its bulk of stone masses of various dimensions, measuring from $\frac{1}{4}$ to $\frac{3}{4}$ of a cubic foot, each rammed into the heart of the wall as the concrete was laid.

486. *Cost of concrete foundation of Fort Tompkins.*—Estimating the cement at 85 cents per barrel, (which was the average price during the summer of 1859, when that portion of the work supplying these data was laid), the broken stone at eight cents per barrel, which is merely the cost of the labor expended in reducing the chippings of the stone-cutters to the proper size for concrete, and allowing six cents per barrel for excavating and screening the sand, which was procured from a deposit close at hand on the premises, and nothing for water, the cost of the concrete was $2.46 per cubic yard, rammed. This was reduced to $2.26 per cubic yard, by the introduction of the unbroken masses of irregular size, allowing nothing for the granite stock thus consumed. These

Cost of concrete of Fort Tompkins.

results are the averages of an entire season's operations, as exhibited in the following table:

487. TOTAL COST OF LABOR AND MATERIAL EXPENDED IN LAYING CONCRETE FOUNDATION AT FORT TOMPKINS, DURING THE YEAR 1849.

Labor.

Wages of sub-overseer 42.2 days at $2 per day		$84 40
" mason setting plank 82.8 days at $2 per day		165 60
" laborers assisting) 153.6 days at $1 per day		153 60
" laborers transporting and ramming concrete 2,971.8 days at $1 per day		2,971 80
Total cost of labor		$3,375 40

Materials.

4,096 casks cement at 85 cents	$3,481 60		
12,288 " sand at 3 cents	368 64		
20,480 " broken stone at 8 cents	1,638 40	5,488 64	
Total cost of labor and materials			$8,864 04
Total number of cubic yards of concrete laid, excluding the stone masses rammed in			3,606$\frac{11}{27}$
Cost per cubic yard of pure concrete			$2 46
Deduct for stone masses rammed in			20
Cost per cubic yard as laid			2 26
If the price of the cement had been the same as at Fort Warren, viz.: $\frac{1}{2}$ cent per lb., the cost of one cubic yard of pure concrete would have been			3.52

488. The following is an analysis of the composition and cost of the concrete employed for laying the foundations of the sea-wall at Lovell's Island, Boston harbor:

1 barrel of cement, 308 lbs. net.... 3.70 cubic feet of paste.....	$1.54
8 cubic feet sand at 51 cents per ton	.20
Labor	.09
Cost of 10 cubic feet mortar	$1.83
Gravel, 30 cubic feet	.28$\frac{1}{2}$
Making concrete, .130 day.... Transporting do., .065 " .... Packing do., .037 "	= .28
Tools, implements, &c.	.13
Cost of 32.30 cubic feet of concrete	2.52$\frac{1}{2}$
Cost of 1 cubic yard laid	$2.11

489. For the concrete backing of the sea-wall at Lovell's Island, the proportions exhibited in the following analysis were adopted:

Cement, 1 cask = 308 lbs. = 3.70 cubic feet paste			$1.54
Sand, 812 lbs. = 7.89 cubic feet dense, producing 9.8 cubic feet mortar			.21
Gravel, 26.4 cubic feet			.25
Making mortar	.065	.24 day.	.40
Making concrete	.02		
Transporting do	.065		
Packing do	.09		
Tools, implements, &c			.12

Cost of 1.09 cubic yard = 2.52
Cost of 1 cubic yard laid = 2.31

Concrete may contain a large proportion of common lime.

490. *Concrete containing common lime.*—Except under circumstances of rare occurrence, concrete may receive a large proportion of the paste of fat lime without serious prejudice to its hydraulic energy and strength, and with great advantage on the score of economy.

491. For founding above water level, the following proportions have been employed in Boston harbor, and elsewhere:

Cost of concrete containing lime.

Cement, 1 barrel = 308 lbs. = 3.70 cub. ft. paste	$1.54
Lime, ⅓ cask, = 2.50 cub. ft paste	.22
Sand, .67 ton = 14.6 cub. ft. dense	.33
Producing .475 cub. yds. mortar = 12.825 cub. ft.	
Making mortar in mills, .475 yds., at 39 c.	.18½
Cost of .475 yds. = 12,825 cubic feet of mortar	$2.27½
Granite, 21.249 cubic feet, at 70 c. per yd.	.55½
Gravel, .61 ton, at 50c per ton	.30½
Making, carrying, and packing concrete	.42—1.28
Cost of 1.355 cub. yd. concrete	$3.55½
Cost of 1 cub. yd. concrete, laid	$2.62½

492. If we increase the volume of lime paste, in the concrete last mentioned, to four times that of the cement paste, thereby giving to the mortar the following composition, viz.:

Increasing the quantity of lime.

Cement paste	1.24 cubic feet.
Lime paste	4.96 " "
Sand	16.6 " "
The corresponding cost per cubic yard of concrete will be	$2.03

493. It is customary to cover the upper tier of arches in casemated fortifications with concrete, formed, for carrying off the water, into ridges and valleys, by a series of inclined plane surfaces, which, after receiving a coating of *lime* mortar, are covered with bituminous mastic. This mastic adheres but indifferently to cement mortar, which, on account of its comparative impermeability to air and moisture, does not absorb the steam and rarified air produced when the hot mastic is applied. The separating medium, thus interposed between the mortar and the mastic, produces air bubbles in the latter while hot, thereby seriously impairing its quality as a covering; objections which do not obtain when lime mortar is used. In cases where the concrete covering is not relied upon in part to render the casemates bomb proof, the principal portion of the roofing, being intended simply to give the required form to the roof surfaces, may be of a cheap quality of concrete, enough cement being used, however, to insure its setting sufficiently quick to prevent interruption to the progress of the work. The composition given above, estimated to cost $2.03 per cubic yard, would perhaps be good enough for this purpose. The upper, or exterior portion, to the depth of five or six inches should be rich and contain no lime. The following is the analysis of that used at Fort Warren for this outer coat:

Bituminous mastic does not adhere well to concrete.

Remedy.

Cement 308 lbs. = 3.70 cub. ft. of paste	1.54
Sand (including waste) 7.4 cub. ft. = .372 ton, at 50 c.	.18½
Broken bricks, 15.4 cub. ft. = .57 cub. yds. at 35 c. per yd.	.20
Making mortar, 7.7 cub. ft. at 39 c. per cub. yd.	.11
Making, transporting, and packing concrete, &c.	.40½
Cost of 18.5 cub. ft. of concrete	$2 44
Cost per cubic yard, laid	3.56

Cost of roofing concrete at Fort Warren.

494. Some blocks of concrete were made in the harbor of New York, in 1860, in the course of these experiments, by injecting a thin paste of light colored Rosendale cement without sand, into boxes filled with coarse gravel and pebbles, and submerged in sea-water. The cement was mixed, in some cases with fresh, in others with sea water, in the proportion by volume of 48 of water to 100 of cement powder. It was poured through a tin pipe $1\frac{1}{2}$ inches in diameter and 18 feet in vertical height. The boxes were $5\frac{9}{10}'' \times 5\frac{9}{10}'' \times 36''$ clear dimensions, and were perforated with small holes, to facilitate the ejection of the water. At the expiration of some weeks, the boxes were taken from the water, and the blocks removed. The cement was found to have penetrated to the remotest corners of the boxes, and to have filled perfectly the interstices in the gravel and pebbles.

Concrete formed by a paste of cement injected under water.

495. The cement mixed with sea-water furnished by no means a stable concrete. A few days after exposure to the air, it began to crack all over the surface, and was very deficient in cohesive strength and solidity.

The paste mixed with sea-water not good.

That mixed with fresh water retained its sharp corners and angles perfectly; no cracks or other evidences of decomposition appeared. The blocks remained solid and compact and when broken for examination it appeared that the adhesion to the pebbles was very good, and that every void was perfectly filled.

496. There is reason to believe that the cream of cement would be improved by the addition of 8 to 10 per cent. of fat lime paste, and that the long pipe can be advantageously replaced by a syringe or force pump of suitable form; for it is evident that the pressure due to the vertical height of the pipe, supposing a perfect fluid to be used, is only partially secured by the semi-fluid cement, and can only be augmented by

The cement paste would be improved by a little lime.

thinning the paste, or by lengthening the pipe. Any arrangement, by means of which a stiffer paste can be injected, would be an improvement.

497. We infer from the foregoing results that a thin paste of Rosendale cement is worthless for concrete, if mixed up with sea-water, while with fresh water, it will harden when injected under water, either fresh or salt, and affords the means of submarine construction, that may be of great value, under certain circumstances.

498. TABLE XVIII.*

Mortars.				Concretes.			Resistance of the concrete to rupture.						
Composition in volumes.			Volume of mortar produced.	Composition in volumes.		Volume of concrete produced.	W, or breaking weight in lbs. found by experiments.			Weight in lbs. of the prism between the supports or a.	Calculated value of R, or resistance per square inch to a force of extension.		
Cement.	Sea sand.	Water.		Mortar.	Wet pebbles.		10 days. lbs.	20 days. lbs.	60 days. lbs.		10 days. lbs.	20 days. lbs.	60 days. lbs.
1	1	.62	1.60	1	1	1.56	1,087	1,093	1,376	92	261	262	328
				½	1	1.03	800	1,322	1,504	99	196	339	360
				⅓	1	1.—	856	1,065	1,480	95	208	257	352
				¼	1	1.—	492	646	481	92	123	160	122
½	1	.43	1.24	1	1	1.45	778	889	1294	90	190	215	299
				⅔	1	1.11	778	954	1016	92	190	231	235
				½	1	1.00	492	668	906	92	123	165	219
⅓	1	.38	1.12	1	1	1.40	404	448	430	88	103	113	109
				⅔	1	1.11	315	463	633	92	83	117	157
				½	1	1.03	271	359	600	88	73	93	148
¼	1	.35	1.05	1	1	1.40	227	346	542	90	63	90	135
				⅔	1	1.14	149	289	437	92	45	77	111
				½	1	1.01	163	240	404	92	48	66	104
⅛	1	.34	1.—	1	1	1.45	141	304	392	88	42	80	101
				⅔	1	1.13	114	218	326	88	37	60	85
				½	1	1.03	114	202	306	88	37	56	77
⅙	1	.32	.96	1	1	1.45	191	192	381	90	55	55	98
				⅔	1	1.13	136	196	337	90	42	56	88
				½	1	1.03	176	181	370	90	51	52	96

* From experiments made at Boulogne-sur-mer by Engineer Voisin, published in "Annales des Ponts et Chaussées" for 1858.

Strength of concretes of natural Boulogne Portland cement.

Table XVIII shows the resistance of prisms of concrete made with the natural Portland cement of Boulogne-sur-mer. The prisms were 5.9056 inches square in cross section, and were broken by a load at the middle, while resting on supports 31.496 inches apart. The formula $W = \frac{2}{3} R \frac{bd^2}{l} - \frac{a}{2}$ was used in deducing the values of R. (See paragraph 554.)

499. TABLE XIX.

GIVING TRIALS MADE AT FORT ADAMS, R. I., BY GENERAL TOTTEN, IN JUNE, JULY, AND AUGUST, 1837, OF THE STRENGTH OF CONCRETES MADE IN DECEMBER, 1836.

No. of trial.	Composition of the mortars.		Cement, 1.00 Sand.... .0 Lime.... .0	Cement, 1.00 Sand.... .50 Lime.... .0	Cement, 1.00 Sand.... .50 Lime.... .25	Cement, 1.00 Sand....1.00 Lime.... .0	Cement, 1.00 Sand....1.00 Lime.... .25	Cement, 1.00 Sand....1.50 Lime.... .0	Cement, 1.00 Sand....1.50 Lime.... .25	Cement, 1.00 Sand....2.00 Lime.... .0	Cement, 1.00 Sand....2.00 Lime.... .25
1	Granite fragments with 1 measure of mortar.		4973	4142	2778	3989	2721	2045	2056	lost	1574
		R =	311	260	174	251	171	129	130	——	99
2	Granite fragments with 2 measures of mortar.		4068	4983	5064	4088	5366	1547	3587	1643	1972
		R =	255	312	317	313	336	——	——	——	——
3	Brick fragments with 1 measure of mortar.		3242	2117	——	4127	3254	1788	2136	1567	3649
		R =	204	133	——	259	205	113	134	98	229
4	Brick fragments with 2 measures of mortar.		2805	5047	2826	4232	1178	3655	3856	2320	4803
		R =	176	316	277	265	74	229	242	146	301
5	Stone gravel with 1 measure of mortar.		1097	1049	1240	1256	1066				
		R =	69	66	78	79	67				
6	Stone gravel with 2 measures of mortar.		3847	4247	2655	1295	3351				
		R =	147	267	167	82	210				
7	Brick gravel with 1 measure of mortar.		5437	6183	3088	lost.	4726				
		R =	341	387	194	——	296				
8	Brick gravel with 2 measures of mortar.		6025	5712	5480	3142	2699				
		R =	377	358	343	197	169				
9	Stone fragments grouted.		3278	1846	2012	1158	1178				
		R =	206	116	127	73	74				
0	Brick fragments grouted.		1634	2305	2869	2726	2770				
		R =	103	145	180	171	111				

The results given in the above table show the weight in

pounds required to break prisms of concrete, $12'' \times 6'' \times 6''$ the distance between the supports being 9 inches. In the table, one measure of mortar corresponds to the volume of voids in the granite, or brick fragments used, and two measures to twice that volume. The values of R are computed for this work from the formula, paragraph 554. The cement was from Ulster county, New York, and the lime from Fort Adams, and was very slightly hydraulic. The volume of voids in the granite and brick fragments was .48 and in the stone and brick fragments .39. The lime paste was passed through a paint mill just before using it, and the coarse fragments were drenched with water just before mixing them with the mortar.

500. The quay walls and certain parts of the Mole of Algiers, as described by M. Poirel in "Mémoires sur les Travaux à la mer," 1841, were built by pouring and ramming concrete into caissons, sunk in position, and lined with tarred cloth, a system borrowed from the Italian engineers, who repair breeches in walls by casting down bags of concrete, from which the mortar exudes in sufficient quantity to bind the whole together. M. Poirel also employed concrete as artificial blocks of 360 cubic feet each, weighing 22 tons, formed and allowed to set in wooden moulds in the air

Mole of Algiers.

For concrete immersed green, the mortar was composed as follows: paste of fat lime, one volume; powdered pozzuolana, two volumes.

The mortar for forming the artificial concrete blocks in the air was composed of: paste of fat lime, 1; powdered pozzuolana, 1; sand 1.

In both cases, one volume of the mortar mixed with one volume of broken stone, gave one volume of concrete in place.

The pozzuolana which succeeded best was the Roman, and it was used in the state of fine powder, being, in fact, quite inert if left in coarse grains, like sea-sand.

501. In executing the new Graving Dock, No. 3, at Toulon,

Graving Dock, No. 3, at Toulon.

M. Noel, the engineer, adopted a concrete foundation, laid under water while green. It was 400 feet long, 100 feet wide, with an average thickness of 15 feet, all in one mass. This area was first enclosed on three sides with close piling, lined on the inside with tarred canvas. Having thus prepared a solid foundation at the requisite level, the concrete hearting of the side, head, and gate walls of the dock was laid under water in caissons of appropriate dimensions, leaving nothing but a lining or revetment of masonry to complete these walls. The total quantity of concrete was 554,300 cubic feet in the bottom, and 418,600 cubic feet in the sides. The mortar of this concrete was composed of one volume of paste of fat lime, and two volumes of finely pulverized Italian pozzuolana.

Jetties at Marseilles.

502. At Marseilles, M. Pascal made use of immense blocks of concrete, allowed to harden in the air three months before immersion, for the protection of the outer or seaward slopes of the jetties, which enclosed the basins and docks of that harbor. The concrete blocks weighed about 22 tons each, and were formed in moulds of 353 cubic feet capacity.

The mortar was composed of three parts of Theil hydraulic lime slaked by immersion and measured in powder, and five parts of sand; for a more active mortar, one-third of the lime was replaced by an equal quantity of Italian pozzuolana. One volume of this mortar was mixed with two parts of broken stone. For concrete to be immersed immediately, two volumes of mortar to three volumes of broken stone were used.

503. M. Pascal expressed his preference for good hydraulic lime, over any pozzuolana mixture, or any natural or artificial cements, provided plenty of time could be allowed to harden before immersion.

504. *The Cherbourg breakwater* is composed of a hearting of rubble, *à pierre perdue*, upon which rests, at the level of ordinary low water, a bed of concrete seven feet thick, composed

of lime mortar and broken stone. The parapet resting on this platform is thirty feet wide at the base and thirty-one feet high towards the sea.

Recently it was found necessary to protect the exposed base of the wall seaward by huge artificial blocks capable by their inertia of resisting the waves of the Atlantic. These blocks contained 720 cubic feet each, and weighed forty-four tons, and were formed by rubble masonry, built up by hand on platforms, in positions subjecting them to submersion at each returning tide.

The stone used was mostly the schistous rock of the neighborhood, and the mortar was composed of either Parker's or Medina cement and sand, or Portland cement and sand. The three cements were sometimes mixed together. The proportions were one volume of Parker's or Medina cement to one and a half of sand, or one volume of Portland cement to two of sand, or intermediate proportions, when the cements were mixed together.

Rubble masonry was preferred to *concrete* for these blocks, as no wooden moulds were required. These blocks have satisfactorily withstood the action of the waves for fourteen years.

505. *At Dover and at Alderney breakwaters* Portland cement has been extensively used in forming artificial blocks, which were laid in the jetties instead of blocks of ashlar. The jetties have ashlar facings or revetments. The blocks of concrete at Dover were composed of—

1 vol. Portland cement,
2 " Coarse shingle.
2 " Fine "
2 " Sand,
4 " Spalls of the Island stone,

Mixed together in a box which revolves eccentrically. The concrete blocks were made in moulds, in which they were allowed to harden eight or ten days, and were then subjected to two or three months' exposure, before submersion by the aid of a diving-bell.

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At Alderney, the concrete is composed of—

1 part Portland cement,
2 " Sand.
4 " Shingle,

Formed in moulds into which irregular masses of rubble, to the extent of thirty-eight or forty per cent. of the whole, are rammed.

Some lime-blocks which were used there were composed of—

2 parts Coarse shingle.
2 " Fine "
1 " Sand,
2 " Spalls of the Island stone.
1 part pound Aberthaw lime.

The cement blocks are tested by lifting them four days after they are made, and the lime-blocks eight days after.

At these ages respectively they were required to sustain their own weight. For handling the blocks, two pieces of stone around which the concrete is rammed, are introduced into each. These stones act as a dovetail, being broader at the bottom than at the top, and have lewis holes in them. The cement blocks were required to be two months old, and the lime-blocks four months in summer and six in winter, before they were placed in the works.

Two cubic yards of cement-concrete required five and a half bushels of dry cement, and the same quantity of the lime-concrete required six and one-eighth cwt. of blue Lias or Aberthaw lime.

506. *In the United States* concrete has for many years been very extensively employed in the construction of the civil and military public works of the country, and recently in the foundations and even the exterior and partition walls of private residences and factories.

507. TABLE XX.

SHOWING THE COST OF VARIOUS KINDS OF MASONRY PER CUBIC YARD, AND THE VOLUMES OF MORTAR REQUIRED FOR EACH.

Kind of masonry.	Volume of mortar.	Quantity of lime required if no cement is used.	Quantity of cement required if no lime is used.	Difference between masonry in cement mortar and masonry in lime mortar.	Cost per cubic yard of masonry laid in.	
					Lime mortar.	Cement mortar.
	u b. ft.	bbls.	bbls.	$ c.	$ c.	$ c.
Rough masonry in rubble stone, or the refuse of quarries called "grout," from $\frac{1}{8}$ to $\frac{1}{10}$ cubic ft. in volume.	10.8	.565	1.22	.90	4.10	5.00
Ordinary masonry in blocks, large and small, not in courses, with their joints rough hammer dressed.	8.1	.423	.92	.62	7.00	7.62
Masonry in large masses, headers and stretchers dovetailed, as ordinarily used for facing sea-walls, sustaining walls, good hammer-dressed beds and joints kept full.	1.0	.05	.11	.08	9.00	9.08
Ordinary masonry in courses of 20 in. to 32 in. rise.	1.5	.08	.17	.12	5.70	
Ordinary masonry in courses of 12 in. to 20 in. rise.	2.0	.105	.22	.16	2.19	
Brick masonry	8.0	.42	.90	.66	5.70	6.40
Concrete (the vol. of voids in the coarse fragments being about .30.)						
of good quality,	11.0*	.54	1.75	1.21	2.19†	3.40†
of medium "	9.0*	.41	1.06	.65	1.56‡	2.21‡
of inferior "	8.0*	.37	.97	.60	1.45§	2.05§
Rubble masonry, dry (*i. e.* without mortar)	.....	.....	.....	.....	3.00 to	3.30

The cost of materials delivered at the work has been assumed to be as follows: cement, $1.20 per barrel; lime, $1.00; bricks, $4.25 per thousand; sand and gravel, 80 cents per ton; granite fragments produced from stone-cutters' chips, at 55 cents per

REMARKS ON TABLE XX.

* These mortars are not exactly identical in the proportion of paste and sand.
† Coarse ingredients entirely of granite.
‡ Coarse ingredients entirely of gravel.
§ Coarse ingredients entirely of gravel.

Note to Second Edition.—With cement at $2.50 per barrel, lime at $2.00, labor at $1.50 per day, and sand close at hand, good concrete is estimated at $6.00 per cubic yard.—Q. A. G.

cubic yard, neglecting the cost of stock; labor, $1.00 per day, and the necessary superintendence. The work is supposed to be of some extent, and the operations to continue without interruption through the season.

For walls under two feet in thickness, the prices in the table will be increased somewhat. The rate of increase for thin hollow concrete walls, which require movable boxing on both faces, will probably reach but not exceed 10 per cent., while for the other kinds of masonry the increase of expense will be more moderate.

CHAPTER VIII.

508. In a memoir submitted to the French Academy of Sciences in the year 1856, entitled "General Considerations upon Hydraulic Materials used for Constructions in the Ocean," to which reference is made in other parts of this work, the authors, MM. Chatoney and Rivot, Engineers of Roads and Bridges, are led, as the results of their experiments, to some deductions somewhat at variance with the established usage of European engineers. As many of the points to which they direct special attention can have no practical interest to American engineers, they will not be noticed here.

Memoir of MM. Chatoney and Rivot.

509. From page 159 of their memoir we quote as follows: "We have supposed until now, that the cements should be tempered with a quantity of water just sufficient to obtain the consistency requisite for working it; but, whenever it is possible, it is better to use pure cement in a semi-fluid condition, viz.: with a great surplus of water; in becoming solid, it rejects the water not necessary for hydration, and its texture is much more compact than when tempered to ordinary consistency; it may be said that the molecules, left to themselves in a more liquid medium, arrange themselves better; they are more watery and carry less air with them; for this double reason the mortars are less porous."

They recommend pure cement to be used with an excess of water.

510. M. Vicat arrays himself against what he terms this new

M. Vicat opposes this doctrine.

doctrine, and pertinently asks how it is possible that this augmentation of volume, due to a surplus of water, can be attended with an increase of density, when the mortars have attained their final hardening. That skilful experimenter at once set to work in his laboratory to disprove this statement of MM. Chatoney and Rivot. For this purpose, glass tubes of equal diameters (nearly two inches) were procured, and into them were introduced, respectively, the several natural cements from Grenoble, Paris, Vassy, and La Valentine, mixed in one case, in the proportion of 50 parts of water to 100 parts of cement, and in another in the proportion of 120 parts of water to 100 of cement. The pastes were stirred with a glass rod until they began to stiffen. The tubes being of equal diameters, the volumes of the several pastes were directly proportional to their altitudes in the tubes.

At the expiration of two months, the glass tubes were carefully broken, the cement cylinders removed, and their relative hardness, weight, and capacity of imbibing water obtained, with the following results:

TABLE XXI.

No.	Condition of the paste.	Hardness	Weight.	Capacity of imbibition.
1	For the stiff paste, after naturally drying in the air,	1.000	1.000	1.000
2	For the diluted paste, after naturally drying in the air,	.075	.375	2.570

511. The experiment was pushed further in the following manner. The semi-fluid condition of the paste favored a subsidence of the heavier particles, which caused greater density at the bottom than at the top of the tube. Other cylinders were formed by pouring in the paste, and allowing it to assume a state of rest, and subsequently to harden without agitation. The relative hardness as indicated by the penetration of the

point was then obtained at the top and bottom of the cylinders, with the following results:

TABLE XXII.

No.	Condition of the paste.	Hardness as measured by the penetration of a point.	
1	Valentine cement tempered to a good consistency.	Top of cylinder,	21
		Bottom of do.	21
2	Same, precipitated spontaneously from a semi-fluid mixture.	Top of do,	00
		Bottom of do.	05
3	Grenoble cement tempered to a good consistency.	Top of do.	33
		Bottom of do.	33
4	Same, precipitated spontaneously from a semi-fluid mixture.	Top of do.	01½
		Bottom of do.	09

512. The results given above were obtained with what are generally termed quick-setting cements. When mixed to a stiff paste, they will set in twenty to thirty minutes. Similar trials were made, and similar results obtained with cements of inferior hydraulic activity, that required two to three hours to set. M. Vicat concludes, therefore, that a large dose of water invariably injures cement mortar. Inspector-General Reibell, who used the Boulogne cement made from the septaria, in 1852, for the works at Cherbourg, found that it did not harden between the stones when employed in a semi-fluid state (*en coulis*). Some of this cement was forwarded to M. Vicat by the Inspector-General for trial, and gave the following results after ninety days immersion:

M. Vicat and Inspector-General Reibell's experience.

TABLE XXIII.

No.	Condition of the paste.	Tenacity per sq. centimetre, (.3937″ × .3937″)
1	For 100 parts Boulogne cement tempered with 50 parts water,	8.20 kilograms.
2	" 100 " " " " " 57 " "	6.45 "
3	" 100 " " " " " 80 " "	3.75 "

These results, says M. Vicat, were found to correspond with those obtained at Cherbourg.

Remarks on the last three Tables.

513. There is, perhaps, little doubt that the results reported by M. Vicat are, in the main, correct, although much depends on the age of the cement, and the manner of its preservation; newly-made cement takes a much firmer consistency with a given quantity of water, than that in which the uncombined quicklime has become spontaneously slaked.

514. *The trials with tubes were greatly exaggerated*, and furnish no conclusive refutation of the deductions of M. Chatoney, for that engineer recommends for his thin paste four parts of water to ten of cement, while M. Vicat used with the same quantity of cement five parts of water to obtain his maximum consistency, and twelve parts for the minimum, being an excess of water equal, in the two cases respectively, to 25 per cent., and 300 per cent. over the maximum quantity adopted by M. Chatoney.

"Portland" cement used *en coulis.*

515. It will be seen that M. Vicat made his trials with the natural cements; M. Chatoney, on the other hand, had reference to the "Portland" cement which had been used by him "to stop the infiltrations of water under the cut stone of the apron of the Florida Dock, at Havre," the beton on which the apron rested having become so decomposed under the influence of sea-water that the pebbles were no longer bound together by the mortar. The following preliminary experiment was made: A box about six and a half feet long, two and a quarter feet wide, and four inches deep was filled with the pebbles used for concrete, and covered up with a board well loaded down with weights. Into one of the corners of this box was then poured through a vertical tube 1.57 inches in diameter, and 17 feet four inches high a mixture of five parts of Portland cement and two parts of water.* M. Chatoney says: "When the box was taken to

* Some blocks of concrete, noticed in another part of this work, were made in this manner on Governor's Island, New York, in the autumn of 1860.

pieces the cement was found to have penetrated among the pebbles to the extremities of the box, and had transformed them into excellent beton, more compact than could have been made by masons upon a stand." This experiment was deemed so satisfactory that the infiltrations under the dock-apron were stopped by an injection of liquid paste of Portland cement. Some of this cement, which, after completely filling the vacant spaces, had overflowed the apron, and attached itself firmly to the cut-stone, was removed and kept in sea-water for testing. It furnished the following results:

516. TABLE XXIV.

Giving the tractile strength of mortars of pure Portland cement mixed to a cream with two-fifths of its volume of water, injected into and kept in sea-water:

Age of mortar.	Weight required to break the prisms by a force of extension.
15 days,	134½ pounds per square inch.
45 "	207⅛ " " "
135 "	233½ " " "

517. It is claimed for the Portland cement by those who have given the subject attention, and are acquainted with its use, that however favorably it may compare with the best natural cements of Europe, when employed as a stiff mortar,—and experiments appear to establish its superiority with singular unanimity,—its most prominent and valuable properties are displayed when employed under conditions similar to those which obtained at Havre, that is, when mixed with a surplus of water, capable of producing a semi-fluid or creamy consistency (*en coulis*). When thus treated, it sets rather slowly, some varieties retaining the plastic condition for hours; and while hardening, it is said to reject a portion of the excess of water.

Alleged superiority of Portland cement.

518. The deductions of M. Vicat in the laboratory from trials with the natural cements of Grenoble, Paris, Vassy, and elsewhere, burnt in the ordinary way, must therefore be received with some caution, when we attempt to compare them with practical results, obtained with a cement produced, as the "Portland" is, under the peculiar condition of a vitrifying heat.

M. Vicat's deductions to be received with caution.

519. It does not appear that any trials of strength were made with concrete formed by the process of injection, practised by M. Chatoney. Compared with the resisting power of the cementing substance itself mixed with an excess of water, such concretes must be strong, as the conditions are peculiarly favorable to the development of the adhesive properties of the cement.*

* M. Vaudrey, Engineer des "Ponts et Chaussées," who succeeded M. Darcel in the service of the Seine Navigation and Paris Bridges, made use of the natural Boulogne "Portland" cement in preference to the Roman, in reconstructing the St. Michel's Bridge in Paris. A notice of this work published in the Annales des Ponts et Chaussées for 1857, volume xiv., furnishes the following extracts:

"Engineers daily meet with occasions for using Roman cement, (natural hydraulic cement). They acknowledge that great inconveniences arise from the mortars setting much too rapidly, which renders it necessary to prepare it in smal quantities at a time. The proportion of cement used generally renders these mortars very expensive. With 'Portland' cement, the mortar can be made up in small quantities and by the most economical process, as the setting begins only after eight hours. The workmen consequently have the time necessary for using the mortar. Moreover with a much smaller percentage, the 'Portland' produces a more resisting mortar than the Roman cement." In reconstructing the St. Michel's bridge, a portion of the old masonry that had stood for two centuries, was left in the buttresses. For the new masonry of these buttresses the mortar was composed of—

1 cubic metre (1.3 cubic yard) of river sand,
250 kilogrammes (550 lbs. avoir.) of Portland cement.

In its fabrication, the sand and cement were first mixed dry, the water being added after these two substances had become thoroughly incorporated. Its amount necessarily varied with the state of dampness of the sand; it was on the average: 125 litres (132.1 quarts) water for 1 cubic metre (1.3 cubic yard) of sand.

The analysis of the cost is:

For 1 cubic metre of sand.....	Fr. 3.20
250 kil. Portland cement (at Fr. .08 per kil.)	20.00
Cost of fabrication	2.50
Price of one cubic metre of mortar	Fr. 25.70

(Which is equal to $3.64 per cubic yard).

520. This seems a suitable place to introduce the results obtained with some American cements, mixed to different degrees of consistency. These are given in the following table:

Trials of American cements.

TABLE XXV.

Showing the ultimate strength of rectangular parallelopipeds of pure cement mortar, $2'' \times 2'' \times 8''$ formed in vertical moulds under varying conditions of consistency and compression, and broken on supports four inches apart, by a pressure from above, midway between the supports. The mortars were kept in a damp place twenty-four hours, and were then immersed and kept in salt water until broken. The numbers from 1 to 23, inclusive, were 59 days old; those from 24 to 59, inclusive, were 320 days old.

"According to the specifications of the contract, the mortar of cement made in the proportion of 3 vol. of sand for 1 vol. of cement, and moulded into prisms .04 metre × .04 metre (1.57 in. × 1.57 in.), and immediately deposited in water must, at the end of eight days, resist, without breaking, the tractile strain of 40 kilogr. (88.16 pounds). This clause at once excludes the Roman cements, which, under these conditions, break under the tractile strain of 12 to 15 kilogr. (26½ to 33 pounds)." "The Boulogne, 'Portland' cement generally bears 80 kilogr. (176.33 pounds). It weighs about 1.100 kilogr. (2.425 pounds) per cubic metre. (68½ pounds per cubic foot)."

"The proportion of 250 kilogr. of cement for one cubic metre of sand corresponds to a quantity of cement less than one fourth that of the sand."

"The prisms bear after eight days a weight of 30 kilogr. (66.1 pounds). This cement was manufactured by MM. Demarle & Co. of Boulogne-sur-mer (see paragraph 87) who delivered it to the works in Paris for eight francs per hundred kilogrammes (67 cents per hundred pounds)."

Mr. Vaudrey further remarks: "When the Roman cements first appeared in the market, their price was far from being so reasonable; I firmly believe that the price of the 'Portland' cement will be considerably reduced after some time. A great many localities possess the elements necessary for the manufacturing of that cement. I shall mention, among them, the layers of marl above those of gypsum at the Buttes Chaumont where some hydraulic lime and Roman cement are already manufactured. However, for the 'Portland' cement, a precise proportion of 21 per cent. of clay is necessary.

"The calcination is a very important element in the manufacturing of all cements; the less calcined they are, the quicker they set; but in proportion as they set quickly, their power of resistance diminishes. I have no confidence in very quick-setting cements."

No. of the mortar.	Kind of cement.	Composition of the mortar.	Pressure per square inch applied while setting.	Penetration of point in inches. 1 impact.	2 impacts.	Weight, in lbs. supported before breaking.	Average breaking wt. of each kind of mortar.
1	James River....	4 vol. dry cement. $2\frac{6}{10}$ vol. water. A thick cream poured into moulds and shaken down.	none	.175	.277	248	
2	"	" " " "	"	.197	.297	236	
3	"	" " " "	"	.296	.410	346	
4	"	" " " "	"	.300	.420	291	281½
5	"	" " " "	"	.330	split	291	
6	"	" " " "	"	.330	split	299	
7	"	" " " "	"	.300	split	275	
8	"	" " " "	"	.300	.400	267	
9	"	4 vol. dry cement. $1\frac{4}{10}$ vol. water. A stiff paste.....	32 lbs.	.075	.125	510	
10	"	" " "	"	.090	.145	447	
11	"	" " "	"	—	—	557	497½
12	"	" " "	"	.122	.185	551	
13	"	" " "	"	.140	.216	416	
14	"	" " A stiff paste well shaken in moulds and rammed.	none	.180	.260	322	
15	"	" " " "	"	.167	.252	291	
16	"	" " " "	"	.190	.280	288	288⅓
17	"	" " " "	"	.180	.250	259	
18	"	4 vol. dry cement. 2 vol. water. Paste rather thin, shaken in moulds, and rammed.	"	split	—	228	
19	"	" " " "	"	split	—	252	
20	"	" " " "	"	.240	.350	259	250⅚
21	"	" " " "	"	.250	.360	291	
22	"	" " " "	"	.250	.350	232	
23	"	" " " "	"	.230	.330	243	
24	"	Pure cement and water, a thin paste.....	32 lbs.	.060	.100	375	
25	"	" " "	"	.070	.120	359	409⅔
26	"	" " "	"	.067	.125	441	
27	"	" " "	"	.067	.116	461	
28	"	" " a stiff paste.....	"	—	—	402	
29	"	" " "	"	.077	.137	371	
30	"	" " "	"	.065	.125	355	392⅔
31	"	" " "	"	.060	.110	425	
32	"	" " "	"	.057	.137	409	
33	Rosendale, Hoffman Brand,	" " a thin paste.....	none.	.112	.200	648	646
34	"	" " "	"	.140	.237	644	
35	"	" " a *very* thin paste.....	"	.122	.227	404	400
36	"	" " "	"	.102	.190	396	
37	"	" " a thin paste.....	32 lbs.	.180	.130	785	
38	"	" " "	"	.175	.130	769	692⅓
39	"	" " "	"	.067	.127	572	
40	"	" " "	"	.070	.120	644	
41	"	" " a stiff paste.....	"	.064	.114	650	
42	"	" " "	"	.057	.110	644	635⅓
43	"	" " "	"	.070	.090	613	
44	Rosendale, Delafield & Baxter.	" " a thin paste.....	"	.100	.180	621	613
45	"	" " "	"	.110	.200	605	
46	"	" " a *very* thin paste.....	none	.150	.240	404	
47	"	" " " "	"	.180	.280	401	
48	"	" " " "	"	.150	.240	409	418
49	"	" " " "	"	.180	.280	413	
50	"	" " " "	"	.177	.277	425	
51	"	" " " "	"	.142	.240	456	
52	"	" " a stiff paste.....	32 lbs.	.052	.090	1134	
53	"	" " "	"	.057	.105	1141	
54	"	" " "	"	.047	.085	808	
55	"	" " "	"	.035	.077	795	871⅓
56	"	" " "	"	.050	.087	816	
57	"	" " "	"	.140	.080	862	
58	"	" " "	"	.037	.075	707	
59	"	" " "	"	.040	.050	767	

GENERAL DEDUCTIONS FROM TABLE XXV.

1st. The two Rosendale cements offer better results than that from James River. The results of the table are rather discrepant.

2d. No great advantage appears to be gained by mixing the paste stiff, provided it is in condition to set under compression. Delafield and Baxter's cement gave much the best results when mixed stiff.

3d. When neither is subjected to compression during setting, a thin paste produces about as strong a mortar as a stiff one. Nos. 1 to 8, and Nos. 14 to 17.

4th. Between the limits of $1\frac{4}{10}$ to $2\frac{6}{10}$ vol. of water to 4 of cement, there is a variation of about 13 per cent. in the average resistance of the mortars, the lowest average resistance corresponding to two vol. of water to four of cement. This result must be regarded as a discrepancy due to imperfect manipulation. Nos. 1 to 8, 14 to 17, and 18 to 23.

Tests of Portland cement used at Cherbourg.

521. From numerous laboratory experiments carried on at Cherbourg, in order to test the quality of the "Portland" cements used in the construction of the breakwater, it was ascertained that their average resistance to a force of traction when mixed stiff and without sand, and kept in salt water 45 days was 266 lbs. It was not customary to reject any whose strength did not exceed 170 to 185 lbs., this being as high a degree of resistance as the cements manufactured for the trade generally attained.

Tractile strength of Roman and artificial Portland cement.

522. Table XXVI. contains results which afford the means of comparing the tractile strength of the Roman and artificial Portland cements. The trials were made by M. Darcel, Engineer of Roads and Bridges, and were reported in the "Annales" for the year 1858. Two varieties of Portland cement, the French (natural), and the English (artificial), and two of Roman, the Paris and the Vassy, were employed. The variations in the two varieties of the same article, were so

slight in both cases, that the differences are not retained in the table. M. Darcel's trials were made in the open air upon quadrangular prisms of 1.57″ × 1.18″ in cross section. "After having dried for six weeks, the prisms were suspended by one extremity supporting at the other extremity a plate which was loaded, until the prisms broke by extension."

TABLE XXVI.

Giving the tractile strength per square inch of cement mortars 42 days old, kept in the open air.

	Proportion of sand for 1 of cement.										
	0	1	2	3	4	5	6	7	8	9	10
	Resistance per square inch, in lbs.										
Portland cement	284½	284½	199⅛	166½	142¼	128	116⅔	106¾	99½	92½	95⅛
Roman cement	142¼	142¼	113¾	92⅓	79⅜	67	57	42⅔	35½	25 6/16	0

Roman and natural and artificial Portland cements without sand.

523. MM. Belgrand and Michelot, from their experiments, give the results, found in the following table, obtained with cement mortars containing no sand. The mortars were kept immersed, and it appeared to be immaterial whether it was in sea or fresh water.

TABLE XXVII.

Kind of cement.	Age of cement.	Resistance to a pulling strain per square inch.
Boulogne (natural) Portland	1 year.	640 to 711 pounds.
English (artificial) Portland	do.	427 to 498 "
Roman cement from "Septaria."	do.	170 to 213 "

Alleged superiority of Boulogne Portland cement.

524. Those gentlemen also state that mortars composed of one volume of Boulogne "Portland" cement and four volumes of sand offer as great a resistance as those composed of one volume of English

"Portland" and two volumes of sand, and are superior to those of Roman cement without sand. This comparison, as regards the Roman cement, is the same as that furnished by Table XXV., from the experiments of M. Darcel.

525. *Some trials made in New York City*, in 1860, in the regular course of these experiments, upon English Portland and Roman cements, supposed to be about three months old, taken from well-conditioned barrels, gave the resistances shown in the following table:

Trials of English Portland and Roman cements in New York.

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526. TABLE XXVIII.

Showing the ultimate strength of rectangular prisms two inches square in cross section, of Portland and Roman cement mortars, which set under a pressure of 32 pounds per square inch, broken on supports four inches apart, by a force applied at the middle.

The mortars were mixed quite stiff, and were kept immersed in sea-water. The cement was measured by volume in loose powder.

No. of mortar.	Kind of cement.	Composition of the mortar.	Age of mortar.	Penetration of point, in inches.		Weight, in lbs. supported before breaking.	Average breaking weight of each kind of mortar
				1 impact.	2 impacts.		
1	English Portland	Pure cement	320 days,	.032	.077	1,521	1,536
2	" "		" "	.057	.105	1,552	
3	" "	1 vol. cement and 1 vol. sand,	" "	.060	.095	1,271	1,263
4	" "	1 " " 1 "	" "	.072	.112	1,255	
5	" "	1 " " 2 "	" "	.057	.090	1,017	950
6	" "	1 " " 2 "	" "	.072	.107	884	
7	English Roman.	1 " " 1 "	20 "	.132	.205	248	242
8	" "	1 " " 1 "	" "	.152	.238	236	
9	" "	1 " " 1 "	100 "	.080	.130	585	585
10	" "	1 " " 1 "	" "	.090	.130	585	

527. From the foregoing we derive the following table:

TABLE XXIX.

Showing the resistance per square inch to a force of extension, of mortars of Roman and Portland cement deduced from Table by the formula $W = \frac{2}{3} R \frac{bd^2}{l} - a^2$

No. of the mortar.	Kind of cement.	Composition of the mortar.	Age of mortar.	Value of R, or tractile strength per square inch.
1	English Portland..	Pure cement.	320 days,	1152 pounds.
2	" "	1 vol. cement, 1 vol. sand,	" "	948 "
3	" "	1 " " 2 " "	" "	713 "
4	English Roman ..	1 " " 1 " "	20 "	182 "
5	" "	1 " " 1 " "	100 "	439 "

Further trials with English Portland cement.

528. Trials were made (see Table XXX.) with a sample of English Portland cement, not obtained from the lot which furnish the results recorded in Table XXVII. The prisms were made of rather stiff mortar, rammed into a mould but not pressed; they were 1″ × 1″ in cross section, were kept in sea-water 270 days, and then broken, on supports three inches apart, by pressure applied to the middle. The cement was measured in volume of loose powder. The table contains the average of many trials. Some of the mortars were tested as many as thirteen times.

TABLE XXX.

No. of the mortar.	Composition of the mortar.	Weight, in pounds, supported before breaking.
1	Pure cement paste,	306
2	Cement, volume 1. Sand, volume 1,	313
3	" " 1. " " 2,	204
4	" " 1. " " 3,	91
5	" " 1. " " 4,	74
6	" " 1. " " 5,	45

Trials of American cement.

529. The only *American mortars* formed in the same mould that were used for the table just given, and hence furnishing a fair comparison, were made of cement from layer No. Nine, at High Falls, Ulster county, New York. It was calcined to a "cinder," and then treated in all respects like mortar No. One of the last table, in regard to age, conditions of submersion, manner of breaking, and every other particular. The results are given below:

TABLE XXXI.

No. of the mortar.	Composition of the mortar.	Weight, in lbs. supported before breaking.	Average breaking weight.
1	Pure cement paste	269	
2	" " "	300	
3	" " "	271	
4	" " "	273	273½
5	" " "	259	
6	" " "	269	

REMARK.—We see that there is no remarkable superiority of strength in the mortars of pure Portland cement, Table XXX., and similar ones of American cement, Table XXXI. The Portland cement may not have been as good as usual.

530. Trials were made with Portland and Roman cements at the London Crystal Palace Exhibition, in 1851. The following data are taken from the report thereon:

Portland and Roman cements tried at London.

1. A prism of neat Portland cement, 4 months old, 4 inches square in cross section, on supports 16 inches apart, broke with 1,580 lbs. at the centre.

2. A prism of Roman cement, from the Harwich stone, same size as No 1, 7 months old, broke at 380 lbs. same bearing. Cement supposed to be defective.

3. A prism of Roman cement, from Sheppey stone, same as No 1, supported 1,100 lbs. before breaking.

4. A prism of Portland cement, 6 months old, 2″ × 2⅛″ cross section, broke with a tractile strain of 2,280 lbs. (equal to 414$\frac{6}{11}$ lbs. per sq. inch).

5. Two 6 in. cubes of Portland stone, cemented with Portland cement, bore 4,500 lbs. tractile strain, when the hook gave way. Cement 4 months old.

6. Two 6 in. cubes, as above, united with Roman cement, broke at 2,780 lbs. (77⅞ lbs. per sq. inch) when 5 months old, by separating from the stone, leaving the cement perfect.

7. A block of neat Portland, 3⅛″ × 2⅛″, one month old, tore asunder with a weight of 3240 lbs. (393⅓ lbs. per sq. inch).

TRIALS IN A HYDRAULIC PRESS.

8. A block, all Portland cement, 18″ high and 9″ × 9″, bore a pressure equal to 108½ tons on the square foot.

9. A mixture of 1 sand and 1 cement bore 80 tons per square foot.

10. do. 4 do. 1 do. do. 80 do. do. do.

11. do. 7 do. 1 do. do. 44½ do. do. do.

12. A block, all Roman cement, broke at 22½ tons.

13. A mixture of 4 sand and 1 Roman cement would not bear any pressure.

14. A block of Portland stone 1½″ × 1″ broke up at 23 cwt.

15. A block of neat cement 12″ × 2¼″ deep × 2½″ horizontally, with supports 9½ in. apart, loaded at centre, broke with 9½ cwt.

16. A block of neat cement 12″ × 2¼″ deep × 2½″ wide, with supports 9 inches apart, scales broke with 25 cwt. on centre. The experiment was repeated, and the cement broke with 42 cwt.

17. A block of 1 volume cement and 2 volumes fine shingle sand, 12″ × 2¼″ deep × 2½″ wide, 8 inches bearing, broke with 10 cwt. on the centre.

18. A fire-brick beam 14 in. wide, 9 inches deep, and 6 ft. 4 in. between the bearings, joined with neat cement, and loaded uniformly over a central space 2 ft 4 in. long, broke through the bricks in two places with a weight of 20¼ cwt.

19. A fire-brick beam, 14″ wide × 10″ deep, with 5 ft. 3 in. between the supports, jointed with neat cement, and loaded over a central space 2ft. 4 in. long, broke (through the bricks) in two places with 30 cwt.

20. Several of the fragments of brick-work, when thrown against a stone with force, broke in all cases through bricks and not through the joints.

NOTE. Experiments made in England show that Portland cement adheres better to the Portland stone than to any other material.

Its advantage for exterior stucco consists in its agreeable color naturally, its power of resisting frost, and its freedom from vegetation.

Adhesion of mortars to solid materials.

531. The trials undertaken to ascertain the adhesion of mortar to the solid materials used in constructions, go to show that such experiments involve many elements of uncertainty, and require to be conducted with great care. The first tests were with Croton Point front bricks, of which a large number were cemented together face to face, at right angles to each other, as represented by Fig. 2, paragraph 32, and kept 320 days. Some were wetted with a sponge every two or three days, while others were kept dry.

In tearing the bricks apart, at the expiration of the time specified, it was found that, in a majority of cases, the surface of contact of the brick and mortar remained intact, the adhesion to the brick overcoming the cohesive strength either of the bricks themselves, or of the mortar composing joint between them. The results, therefore, although interesting for other reasons, furnish no entirely satisfactory measure of the power of adhesion. In fact, they are fair indications of the resistance offered by these materials to a force of traction, and incidentally, of the time which must elapse before the adhesive power to bricks of the several mortars tried exceeds this limit of resistance.

532. In giving the results, it will be necessary, in many instances, to give a diagram of the surface of fracture. In such cases, the splitting of the joints whereby a portion of the mortars remains upon each brick, is represented by a dotted surface, the tearing out of a part of the brick is shown by a surface shaded in parallel lines; and a clean separation from the bricks by a plain white surface. When the fracture takes place continuously either in brick or mortar, or is a continuous separation of one from the other, or when the end of a brick breaks off, the fact is so stated, and no diagram given. Each marginal sketch, Table XXXII., represents the area of the entire joint between two bricks.

Diagram of results.

533. The bricks were left on shelves in the open air, and those marked thus, *, were wetted with a sponge two or three times a week.

534. TABLE XXXII.

Showing the resistance which Croton bricks cemented together crosswise, in pairs, face to face, offer to a force of traction applied at right angles to the surfaces of contact. The "siftings" used in some of the mortars are the coarse particles of unground cement, which would not pass wire sieve No. 80. Age of mortars, 320 days.

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaki'g weight by force of traction, in lbs.	Remarks.
1	Delafield & Baxter....	Stiff paste of pure cement	1,097	Fig *a*.
2	"	" "	1,101	End of brick broke off.
3*	"	" "	less than 420	Fig. *b*.
4*	"	" "	843	End of brick broke off.

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaki'g weight by force of traction, in lbs.	Remarks.
5	Lawrence Cement Co..	Stiff paste of pure cement.....	898	Fig. *c*.
6	"	" "	1,258	End of brick broke off.
7*	"	" "	1,242	Continuous fracture in the brick.
8*	"	" "	1,284	" " "
9	"	" "	1,398	End of brick broke off.
10	Kingston & Rosendale.	" "	1,227	Fig. *d*.
11	"	" "	969	End of brick broke off.
12*	"	"	836	Fig. *e*.
13*	"	" "	1,284	End of brick broke off.
14	"	" "	1,055	" " "
15	Hancock, Maryland...	" "	648	Fig. *f*.
16	"	" "	777	End of brick broke off.
17	"	" "	1,023	Fig. *g*.
18	"	"	617	Fig. *h*.
19	Newark & Rosendale..	" "	1,213	End of brick broke off.
20*	James River	" "	859	Fig. *i*.
21	Delafield & Baxter....	Cement in powder 8, siftings 1.	1,278	Brick broke off.
22	"	" "	820	Fig. *j*.
23	"	Cement in powder 4, siftings 1.	979	Fig. *k*.

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaki'g weight by force of traction, in lbs.	Remarks.
24*	Delafield & Baxter....	Cement in powder 4, siftings 1.	843	Fig. *l.*
25	"	Cement in powder 2, siftings 1.	1,132	End of brick broke off.
26*	"	" "	1,211	Broke out a continuous piece in the brick averaging ¼ to ⅜ in. thick.
27	"	Cement in powder 1, siftings 1.	1,310	Fig. *m.*
28*	"	" "	1,246	End of brick broke off.
29	"	" "	1,180	Fig. *n,*
30	"	" "	1,043	Fig. *o.*
31	"	Cement in powder 1, siftings 2.	1,029	Fig. *p.*
32*	"	" "	893	Fig. *q.*
33*	"	" "	812	Fig. *r.*
34	"	" "	570	Continuous separation from the brick.
35	"	" "	682	" " "
36	"	" "	1,192	Brick broke off.
37	"	Cement in powder 4, sand 1 ...	1,096	" "
38*	"	" "	1,023	Fig. *s.*
39	"	" "	974	Fig. *t.*
40	"	" "	1,055	Fig. *u.*

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaking weight by force of traction, in lbs.	Remarks.
41	Delafield & Baxter....	Cement in powder 4, sand 1....	1,023	Fig. *v.*
42	"	" "	1,420	Brick broke off.
43*	"	" "	763	Continuous splitting through the mortar.
44	"	" "	1,023	Fig. *w.*
45	"	Cement in powder 2, sand 1....	1,030	Fig. *x.*
46	"	" "	1,113	Fig. *y.*
47	"	" "	1,070	Continuous splitting through the mortar.
48*	"	" "	843	Fig. *z.*
49	"	Cement in powder 1, sand 1....	420	Fig A.
50	"	" "	732	Continuous splitting through the mortar.
51*	"	" "	812	Fig B.
52*	"	" "	523	Fig. C.
53	"	Cement in powder 1, sand 2 ...	367	Continuous separation from brick. Sand probably defective.
54	"	" "	260	Fig D.
55*	"	" "	491	Fig. E.

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaki'g weight by force of traction, in lbs.	Remarks.
56	James River.....	Cement in powder 8, sand 1....	978	Fig. F.
57*		" "	812	Fig G.
58		Cement in powder 4, sand 1....	992	Fig. H.
59		" "	300	Continuous separation from the brick.
60.		Cement in powder 1, sand 1....	740	" " "
61		Cement in powder 1, sand 2....	392	" " "
62	Newark Lime and Cement Mfg. Co.	Stiff paste of pure cement.....	1 001	Brick broke off.
63*	"	" "	1,492	Fig. I.
64*	"	" "	259	Fig. J. defective.
65	"	" "	1,451	Fig. K.
66	"	Cement in powder 1, sand 1....	913	Fig. L.
67	"	" "	685	Fig. M.
68*	"	" "	1,036	Centinuous splitting through the mortar.
69	"	" "	608	Fig. N.
70	"	Cement in powder 1, sand 2....	322	Fig. O.

No. of mortar.	Kind of cement.	Composition of mortar. The measurements are by volume.	Breaki'g weight by force of traction, in lbs.	Remarks.
71	Newark Lime and Cement Mfg. Co.	Cement in powder 1, sand 2...	393	Fig. P.
72	"	" "	634	Fig. Q.
73	"	" "	346	Continuous separation from the brick.

535. *The positive deductions from the foregoing table* appear to be as follows:

1st. That particles of unground cement exceeding $\frac{1}{50}$ inch in diameter may be allowed in cement paste without sand to the extent of fifty per cent. of the whole, without detriment to its adhesive or cohesive properties, while a corresponding proportion of sand injures the strength of the mortars in these respects about forty per cent.

2d. That when these unground particles exist in the cement paste to the extent of sixty-six per cent. of the whole, the adhesive strength is diminished about twenty-eight per cent. For a corresponding proportion of sand, the diminution is sixty-eight per cent.

3d. The addition of these siftings exercises a less injurious effect upon the cohesive than upon the adhesive property of cement. The converse is true when sand, instead of siftings, is used.

4th. In all the mixtures with siftings, even when the latter amounted to sixty-six per cent. of the whole, the cohesive strength of the mortars exceeded its adhesion to the bricks. The same results appear to exist when the siftings are replaced by sand, until the volume of the latter exceeds twenty per cent. of the whole, after which the adhesion exceeds the cohesion.

5th. At the age of 320 days (and perhaps considerably within that period), the cohesive strength of pure cement mortar exceeds that of Croton front bricks. The converse is true when the mortar contains fifty per cent. or more of sand.

6th. When cement is to be used without sand, as may be the case when grouting is resorted to, or when old walls are to be repaired by injections of thin paste, there is no advantage in having it ground to an impalpable powder.

536. The ingenious device mentioned below, for laying stone-masonry in cement-mortar under water, was suggested to me by Major B. S. Alexander,

Device for laying stone under water

Corps of Engineers, and was, I believe, practised by that officer in the construction of the Minot's Ledge Light-House, Boston harbor. It consists in protecting the mortar from the dissolving action of the water during the descent of the stone to its bed, by an envelope of muslin sufficiently loose in texture to allow the mortar to ooze through between the fibres, and thus form a bond with the stone previously laid. The idea is analogous to that followed by some Italian engineers in repairing and protecting submarine masonry by concrete, rammed into position in bags of loose, open texture. It may be applied in the following manner, viz.: a piece of muslin of suitable quality, and somewhat larger than the bed of the stone to be laid, is first spread out on a horizontal surface and covered with a coat of mortar of the thickness desired in the work, and of an area somewhat exceeding that of the bed of the stone. On this mortar the stone is then carefully placed and allowed to remain there until the mortar begins to stiffen a little, the margin of the cloth exterior to the stone having been folded up against the sides of the latter, and secured there by cords leading over the top. The stone is then lowered to its position on the wall, rammed into place, and not again disturbed.

537. Some trials made with a view to test the efficacy of this method of construction, although giving discrepant results, show, that if applied with care, it may be made to subserve a good purpose. Bricks were cemented together in pairs, as shown in the table last given. Some of them had cement paste only between them, others had a single layer of muslin next to one of the bricks, and others had muslin in the centre of the mortar joint. Other trials were made with prisms, $2'' \times 2''$ in cross section, with a layer of muslin extended transversely across and through the prism, midway between the supports on which the prisms were broken.

Test of device above mentioned.

538. *Cement paste without sand* was used in all cases, and

the samples were ninety-six days old when broken. Water was applied to them with a sponge two or three times a week, during the entire period. All the bricks were cemented while thoroughly wet. Table XXXIII. contains the results. The numbers 15, 16, 17, and 18 were dipped in sea-water just before being cemented.

Same continued.

539. TABLE XXXIII.

Showing the *adhesive and cohesive strength* which mortars of pure cement paste can attain, through a layer of com-

No. of the trial.	Mode of trial.	Breaking weight, in lbs.	Remarks.
1	Two wet bricks cemented together, without muslin.....	572	Fig. R.
2	" " " "	279	Continuous separation from brick.
3	" " " "	884	Fig. S.
4	" " " "	939	Fig. T.
5	" " " "	908	End of brick broke off.
6	" " " "	572	Continuous separation from brick.
7	" " " with wet muslin in the middle of the joint.	82	" " "
8	" " " " "	94	Separated along the muslin.
9	" " " " "	106	" " "
10	" " " with muslin soaked in cream of cement next to one of them	978	End of brick broke off.
11	" " " " "	709	Separated along the muslin.
12	" " " " "	1153	End of brick broke off.
13	" " " " "	572	Separated along the muslin.
14	" " " " "	719	" " "
15	" " " muslin soaked in cream of cement, and bricks dipped in sea-water.	1153	" " "
16	" " " " "	197	" " "
17	" " " " "	872	Continuous separation from brick.
18	" " " " "	185	" " "

mon thin muslin. The mortar set under a pressure of thirty-eight pounds per square inch, or about 500 pounds on the pair of bricks. Age of mortar, ninety-six days. Same continued.

540. OBSERVATIONS ON THE FOREGOING TABLE.

1. The average resistance, where there is a continuous separation from the muslin, is 507 pounds.
2. The average resistance, where there is a continuous separation from the brick, and no muslin was used, is 425 pounds.
3. The average resistance, where there is a continuous separation from the brick, and muslin was used, is 446 pounds.
4. The average resistance of all the cases where muslin was used, is 568 pounds.
5. The average resistance of all the cases where muslin was not used, is 692 pounds.
6. The case of muslin soaked in cream of cement next to one of the bricks, gave the best average result, viz.: 826 pounds; the next best being when the bricks are put together without muslin, which gave an average of 692 pounds.
7. The three greatest resistances in the above table were obtained when muslin was used. In two of these (Nos. 10 and 12), the end of one brick broke off; in the third, (No. 15,) the separation took place continuously along the muslin.
8. The worst results, when muslin was used, were obtained when the latter was placed in the centre of joint, and not in contact with either brick, the difference being very considerable, as an inspection of the table will show.

The muslin used in these trials was much thicker than would be necessary in practice.

541. TABLE XXXIV.

Showing the *strength of rectangular prisms* $2'' \times 2''$ in cross-section, some of them having a layer of muslin transversely across the prisms, midway between the supports, and some having none. The prisms were ninety-six days old, of pure cement paste, the supports four inches apart. The pressure was applied in the middle. Other trials with muslin.

No. of sample.	Nature of test.	Breaking weight, in lbs.	Remarks.
1	Piece of muslin transversely across the prism	113	Broke along the muslin.
2	" " " "	103	" " "
3	No muslin was used.....	353	
4	" "	337	
5	" "	322	
6	" "	304	

542. OBSERVATIONS ON THE FOREGOING TABLE.

1. The average breaking weight of the prisms containing muslin, is 107 pounds; and of those containing no muslin, 329 pounds.
2. The 8th observation of Table XXXIII. is corroborated, viz.: that the most disadvantageous place for the muslin is in the body of the mortar.
3. With thin muslin of loose texture, both the adhesion and cohesion through the muslin would undoubtedly be much greater than the foregoing Tables (XXXIII. and XXXIV.) indicate.

543. TABLE XXXV.

The effect of the sand on the adhesive properties of mortars.

Showing the *adhesion to Croton front bricks and fine cut granite*, of mortars containing different proportions of sand. The mortar was of the consistency ordinarily used for brick masonry, and the bricks were used wet, and were pressed well together by hand. They were wetted with fresh water every alternate day for 29 days, the age of the mortar when tested. Each result is the average of five trials. The right-hand column shows the ratio of the adhesive strength of the several mortars, assuming that of pure cement to be 1.

No. of mortar.	Composition of the mortar.	Materials cemented.	Weight in lbs. required to tear the bricks apart.	Adhesion per square inch, in lbs.	Ratio of adhesion.
1	Pure cement paste.....	Croton bricks...	421	30.8	1
2	1 vol. cement powder, 1 vol. sand...	" " ..	215	15.7	$\frac{51}{100}$
3	1 " " " 2 " ...	" " ..	169	12.3	$\frac{40}{100}$
4	1 " " " 3 " ...	" " ..	94	6.8	$\frac{22}{100}$
5	1 " " " 4 " ...	" " ..	71	5.2	$\frac{17}{100}$
6	1 " " " 5 " ...	" " ..	59	4.3	$\frac{14}{100}$
7	1 " " " 6 " ...	" " ..	45	3.2	$\frac{11}{100}$
8	Pure cement paste.....	Fine cut granite.	$440\frac{2}{3}$	27.5	1
9	1 vol. cement powder, 1 vol. sand...	" "	$332\frac{2}{3}$	20.8	$\frac{75}{100}$
10	1 " " " 2 " ...	" "	201	12.6	$\frac{46}{100}$
11	1 " " " 3 " ...	" "	$146\frac{2}{3}$	9.2	$\frac{33}{100}$
12	1 " " " 4 " ...	" "	127	7.9	$\frac{29}{100}$

544. The adhesion of mortars to stone or bricks varies considerably among the different kinds of these materials, and particularly with their porosity.

With the same material, it varies with the consistency of the mortar, and the quantity of sand which it contains.

545. TABLE XXXVI.

Showing the *adhesion to very fine cut granite* of pure cement made by the Newark & Rosendale Co., mixed with different proportions of water. The blocks measured $4'' \times 8''$ on the face, and were cemented together in pairs, face to face, at right angles to each other, and kept in fresh water. The stones were pressed together by hand, as in laying bricks, and were pulled apart at the expiration of 96 days by the device, shown in Fig. 5.

No. of the mortar.	Composition of the mortar.	Weight required to tear stones asunder, in lbs.	Average adhesion per square inch.
1	1 vol. loose, dry cement, and $\frac{1}{4}$ vol. water. Consistency of cream.....	330	
2	" " " " " "	330	20¼ lbs.
3	" " " " " "	337	
4	" " " " " "	314	
5	1 vol. loose, dry cement, and $\frac{42}{100}$ vol. water. Consistency of very thick cream	611	
6	" " " " " " "	584	37¼ "
7	" " " " " " "	591	
8	" " " " " " "	599	
9	1 vol. loose, dry cement, and $\frac{33}{100}$ vol. water. Consistency of ordinary mortar.	454	
10	" " " " " " "	490	
11	" " " " " " "	449	29$\frac{1}{7}$ "
12	" " " " " " "	472	

546. For the sake of economy, it is customary to add lime to cement mortars, and this may be done, to a considerable extent, when in positions where hydraulic activity and strength are not required in an eminent degree. The following table contains the results of trials with cement paste and mixtures of cement and lime paste, without sand. The cement was the dark Rosendale of excellent quality.

Lime used for the sake of economy.

547. TABLE XXXVII.

Showing the *ultimate strength of rectangular parallelopipeds* ($2'' \times 2'' \times 8''$) of cement paste, and mixtures of cement and lime paste without sand, formed in vertical moulds, under a pressure of 32 lbs. per superficial inch, and broken when 95 days

old, on supports 4 inches apart, by a force applied at the middle. The mortars were kept in sea-water from the time they were one day old.

No. of the mortar.	Composition of the cement.	Penetration of the point in inches.		Weight, in lbs. supported before breaking.	Average breaking weight of each kind of mortar.
		1 impact.	2 impacts.		
1	Pure cement paste. (Average of two trials.)	.114	.195	994	
2	" " " "	.112	.163	957	1,002½ lbs.
3	" " " "	.117	.192	1,025	
4	" " " "	.107	.187	1,034	
5	Cement paste, 1 vol. Lime paste, ½ vol.....	.155	.250	1,000	
6	" " " "	.160	.250	996	979¾ "
7	" " " "	.147	.245	992	
8	" " " "	—	—	931	
9	" " " ¼ vol.....	.155	.250	863	
10	" " " "	.155	.265	847	816 "
11	" " " "	.150	.200	785	
12	" " " "	.159	.195	769	
13	" " " ¼ vol.....	.12[illegible]	.200	597	
14	" " " "	.200	.300	570	565½ "
15	" " " "	.180	.220	513	
16	" " " "	—	—	582	
17	" " " 1vol.....	.187	.395	597	
18	" " " "	.180	.295	574	569¾ "
19	" " " "	.207	.325	558	
20	" " " "	.210	.330	550	
21	" ¼ vol. " 1 vol.....	.180	.300	365	
22	" " " "	.200	.320	363	364½ "
23	" " " "	.180	.293	355	
24	" " " "	.180	.290	375	
25	" ½ vol. " "	.200	.300	339	
26	" " " "	.220	.340	316	305¼ "
27	" " " "	.230	.260	286	
28	" " " "	.270	.380	280	

548. *Other mortars* of light colored Rosendale cements and lime, mixed, formed into blocks of the same size, preserved and broken in precisely the same manner as the foregoing, gave the following results when 95 days old. The average of four trials is given in each case.

TABLE XXXVIII.

No. of the mortar.	Composition of the mortar.	Breaking weight, in lbs.
1	Cement paste, 1 volume. Limo paste, ⅓ volume.....	738
2	" 1 " " ¼ "	723½
3	" 1 " " ⅔ "	732
4	" 1 " " 1 "	608

Effect of lime on the strength of cement mortar.

549. *Observations on Tables XXXVII. and XXXVIII.*—1st. We infer from the last tables (XXXVII. and XXXVIII.), that the dark

colored Rosendale cements are less able to sustain a large dose of lime than those that are light colored, and that the latter suffer no serious deterioration of strength until the amount of lime paste exceeds the amount of cement paste.

It does not necessarily follow that the ingredients which confer color on the cement are the cause, either immediate or remote, of this difference. The light colored Rosendale cements are confined to one locality, that of High Falls, and it may be that local causes, operated at the period of, or subsequent to their deposition, which so modified or changed the molecular or chemical condition of some of the ingredients, as to cause this variation, and at the same time be beyond the reach of ordinary analytical research.

550. 2d. In Tables XXXVII. and XXXVIII., no record is made of the effects which the addition of lime has on the hydraulic activity of the cement. In regard to this point, however, numerous trials show that a gang composed of equal proportions of the pastes of Rosendale cement and lime is sufficiently quick setting for all purposes, except when immediate submersion is required; and possesses, besides, the positive advantage over pure cement of coming to the hands of the masons in a better working condition, and is not liable to have its incipient set constantly disturbed on the mortar board, and its ultimate strength thereby impaired by remixing. There is a remarkable difference in the capacity of cements to withstand this degrading treatment. The extent to which they are affected by it seems to vary directly with their hydraulic activity. Thus, the Rosendale cements, which require 25 to 30 minutes to set at 65° F., will bear reworking much better than those James and Potomac River cements, which harden in five or six minutes. We would expect that the extent of the disturbance of the crystallization would be in direct proportion to the hydraulic activity.

Effect of lime on the hydraulic activity of cement mortars.

551. *The use of alkaline silicates* (*soluble glass*) as a means

of conferring hydraulic energy upon fat lime has been reverted to in foregoing portions of this work. Experiments uniformly indicate that its efficiency for such purposes, has been overrated. It may, and probably can be advantageously applied to the reclamation of the intermediate limes, (those in which the hydraulic energy is exerted powerfully and rapidly when first mixed, but which soon yield and fall down under the action of the sluggish free lime present); but for fat limes, they appear so unsuitable, that even the statements of M. Kuhlmann himself are insufficient to authorize their use. When added to the intermediate limes, they appear to exert their influence by giving up their silica to the free lime present, thus neutralizing or perhaps only retarding its action, until the hydraulic principle has time to exert its indurating power.

Effect of soluble glass on the strength of mortars.

552. Presuming, under ordinary circumstances, that the addition of soluble glass to a paste of fat lime not only conferred hydraulicity, but augmented the strength of the mortars, some trials were undertaken with the double silicate of potash and soda, in order to test its relative value when thus employed, as compared with hydraulic cement itself. The specific gravity of the soluble glass used was 39° Beaumé, at 62° F. Prisms of the usual size were made and kept in the air ninety-five days, when they were broken in the usual manner, on supports four inches apart. In the following table, the breaking weights are given in the right hand column. The first and second samples were formed under a pressure of 32 pounds per square inch, the others without pressure.

The adhesion to bricks cemented together transversely is as follows:

For mortar of	limepaste	1.0	93¾ lbs.
	sand	3.0	
For mortar of	limepaste	1.0	57½ lbs.
	sand	3.0	
	soluble glass	.125	

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TABLE XXXIX.

No. of the mortar.	Composition of the mortar, in volumes.	Weight, in lbs. supported before breaking.
1	Lime paste, 1.0, sand, 2.0, soluble glass, .11	40
2	" 1.0, " 2.0, " " .11	54
3	" 1.0, " 2.0	77⅔
4	" 1.0, " 2.0	67½
5	" 1.0, " 3.0	65
6	" 1.0, " 3.0, soluble glass, .08	24½
7	" 1.0, " 3.0, " " .10	23
8	" 1.0, " 3.0, " " .125	18
9	" 1.0, " 3.0, cement paste .50	182⅔
10	" 1.0, " 3.0, " " .33	166⅔
11	" 1.0, " 3.0, " " .25	92
12	" 1.0, " 3.0, " " .166	94⅔

553. From the foregoing results, which are the averages of many trials, it may be inferred that the double alkaline silicate, while it renders common mortar hydraulic, injures its strength and its adhesive properties, and is greatly inferior to cement as a hydraulic agent, in both efficiency and economy, irrespective of the degree of energy required. At the same time, it is conceded that in many cases, particularly for hardening soft and porous stones and concrete walls or stucco work, after these are well dried, it is of value when judiciously applied. Its use has, however, been attended with many failures, even in France, where the subject has received much attention, and we are yet without an easy and entirely practicable method of manipulation, that can safely be intrusted to the hands of ordinary mechanics. Silicate of soda should be employed rarely if at all.

It injures the strength and adhesive properties of mortars.

554. The experiments undertaken to ascertain the law of progressive increase in the strength and hardness of mortars of American cements do not extend over a very large period of time. The results obtained, however, afford the means of a very fair comparison between the strength of these mortars and some placed on trial at Toulon, with a view to determine the combinations

Increase of strength and hardness of mortars.

to be used in the construction of the dock in that harbor, under the superintendence of M. Noël, Engineer-in-chief of Roads and Bridges. The trials at Toulon were made during the years 1840 to 1844, upon rectangular prisms 1.57 inches wide by .984 inches deep; they were broken on supports 2.36 inches apart, by a pressure at the middle.

A comparison of the results obtained in the two cases has been made by using the formulas:

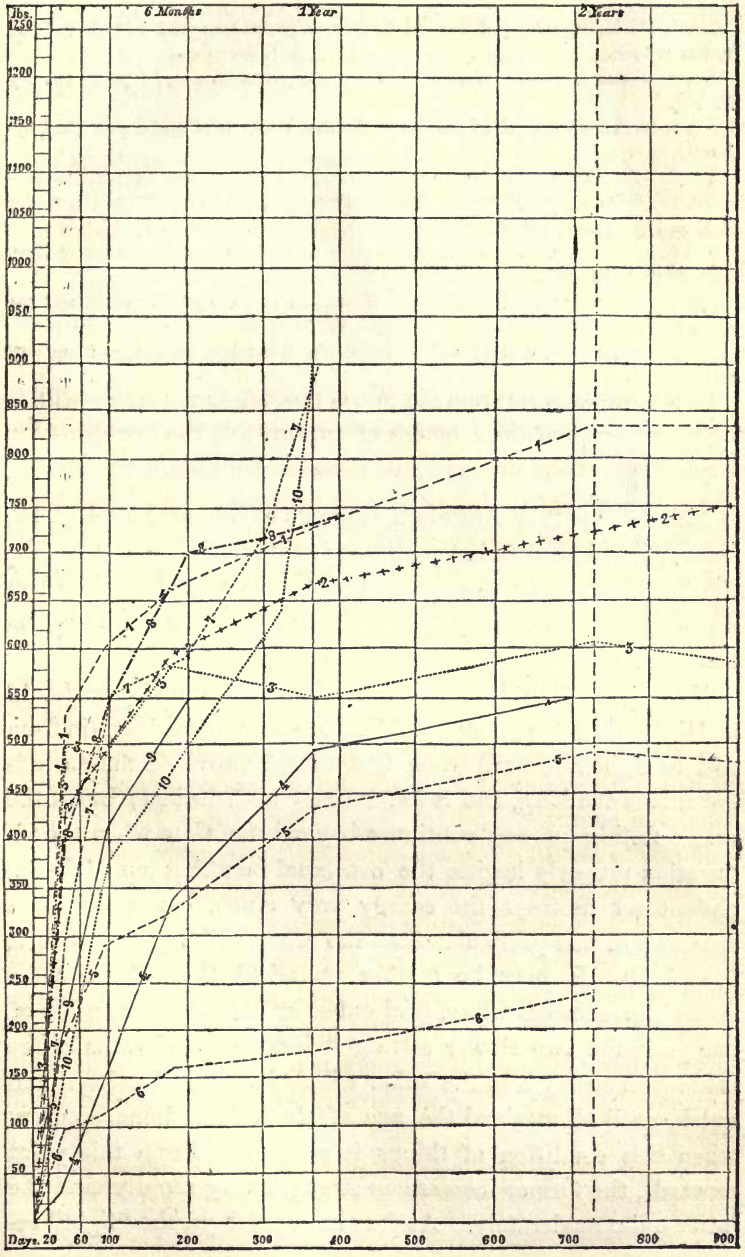
$$(1.)\ W = \tfrac{2}{3} R \frac{bd}{l} - \frac{a}{2} \qquad (2.)\ W' = \tfrac{2}{3} R \frac{b'd'^2}{l'} - \frac{a'}{2}$$

In the general formula (1) W represents the weight which the prism bears at the moment of rupture; b, the breadth, and d, the depth of the prism; l, the distance between the supports, and a, the weight of that portion of the prism represented by l.

The value of R, the co-efficient of rupture, having been obtained from the above equation from M. Noël's prisms, by substituting for W, b, d, l, and a, their known values as reported we readily obtained the value W′ for M. Noël's mortar when the prisms are supposed to be two inches square in cross section, and broken on supports four inches apart, like the American mortars, by substituting in equation (2) the deduced value of R, and the value of b', d', l', and a', corresponding to the American prisms.

555. *The results of the computations* above mentioned, which are the resistances to rupture of rectangular prisms 2″ × 2″ in cross section, resting on supports four inches apart, are given in Fig. 56, by curves constructed with abscissas, which represent the resistances or breaking weights, laid down, to a scale of $\frac{1}{10}$ of an inch to 20 pounds, and with ordinates, which represent the age of the mortars to a scale of $\frac{1}{10}$ of an inch to twenty-five days. The mortars were kept in salt water until broken.

The proportions of cement, lime, and sand are given by volume in all cases.


Lbs.
1250
1200
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1100
1050
1000
950
900
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800
750
700
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400
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250
200
150
100
50
6 Months
1 Year
2 Years
Days. 20
60
100
200
300
400
500
600
700
800
900

19 Fig. 55.

No. 1. Mortar composed of two parts Roman pozzuolana and 1.50 parts Theil hydraulic lime.

No. 2. Mortar composed of two parts Roman pozzuolana and 1 part ordinary lime.

No. 3. Mortar composed of two parts Roman pozzuolana and 1 part Theil hydraulic lime.

No. 4. Mortar composed of two parts sea-sand and 1 part Theil hydraulic lime.

No. 5. Mortar composed of one part Roman pozzuolana, one part Theil hydraulic lime, and one part sea-sand.

No. 6. Mortar composed of one part Roman pozzuolana, one part ordinary lime, and one part sea-sand.

No. 7. Mortar composed of one part Rosendale and Kingston cement and one part sand.

No. 8. Mortar composed of one part Ogden's Rosendale cement, and one part sand.

No. 9. Mortar composed of one part Hudson River cement, and one part sand.

No. 10. Mortar composed of one part Lawrenceville Cement Manufacturing Co., and one part sand.

556. Of the four American cements represented in Fig. 56, Nos. 7, 9, and 10 are what are known as "dark" colored, and take the initial set, so as to support the $\frac{1}{12}$ inch wire, loaded to $\frac{1}{4}$ of a pound, in from twenty-five to thirty minutes, at a temperature of 65° F.

No. 8 is a "light" cement, manufactured from Layer No. 16 at High Falls, (see paragraph 55). It sets very rapidly, (in from five to eight minutes,) when first mixed, provided the paste is not mixed too long, and is left entirely undisturbed; but if the manipulating process continues beyond the time when the induration properly begins, the continual breaking up of the incipient set destroys the energy very much. It is far more sensitive in this particular than the slower acting cements, 7, 9, and 10. It may be further remarked that of the three American cements whose trial extended through the period of one year, the two slower setting "dark" colored varieties are inferior in strength to the other which is "light" colored and quick, until all attained the age of about three hundred days, when this condition of things is reversed. From this point onwards, the former increase in strength very rapidly, and the latter quite moderately. At four hundred days, the "light" ce-

ment is no stronger than a mortar of $1\frac{1}{2}$ parts Theil hydraulic lime and 2 parts of Roman pozzuolana, (curve 1).

557. TABLE XL.

Showing the *strength of mortars of various cements* made into prisms $2'' \times 2'' \times 8''$ in vertical moulds, under a pressure of 32 pounds per square inch, and broken on supports four inches apart, by a pressure midway between the supports. The prisms were kept in sea-water after the first 24 hours, and were 320 days old when broken. The breaking weights given are averaged from many trials. The cement was measured in powder.

Strength of mortars of sundry cements.

No. of the mortars.	Kind of cement used.	Breaking weights of mortars composed of		
		Pure cement.	Cement, vol. 1, Sand, vol. 1.	Cement, vol. 1, Sand, vol. 2.
		lbs.	lbs.	lbs.
1	English Portland (artificial)	1,536	1,260	950
2	Cumberland, Md.	954	920	558
3	Newark and Rosendale	841	560	500
4	Delafield and Baxter (Rosendale)	836	692	532
5	"Hoffman" Rosendale	849	607	——
6	"Lawrence" Rosendale	777	——	——
7	Round Top, Md.	——	600	——
8	Utica, Ill.	732	756	562
9	Shepherdstown, Va.	747	618	450
10	Akron, N. Y.	764	651	603
11	Kingston and Rosendale	720	556	500
12	Sandusky, Ohio	554	464	——
13	James River, Va.	——	623	638
14	* Roman cement, Scotland	553	——	380
	The following were broken when one year old:			
15	Lawrenceville Manuf. Co. (Rosendale)	——	910	——
16	Sandusky, Ohio	802	——	——
17	Kensington, Ct.	954	709	506
18	Lawrence Cem't Co. (Rosendale) "Hoffman" Brand.	875	911	——
19	Round Top, Md.	——	840	——

* This cement appeared to be inferior in hydraulic energy to Roman cement generally, and had probably been injured by age and exposure.

558. From *General Treussart's experiments* with mortars of fat lime and trass, or pozzuolana, it may be inferred that these two substances possess very

Gen. Treussart's experiments.

nearly equal merit, as agents for conferring strength and hydraulic energy on common mortar. He says pozzuolana gave rather the better results with the same kind of lime; although "in general there was little difference between the trass and the pozzuolana used."

The results given in the following table were obtained by that engineer, and are introduced here as affording a just medium of comparison between such mortars, and those of the same age (one year) recorded in the table last given. (Table XL.)

559. TABLE XLI.

Breaking weights of pozzuolana and trass mortars, one year old, formed into prisms $2'' \times 2'' \times 6''$, and resting on supports four inches apart. The lime was slaked to powder and measured in that condition. The prisms had been kept in water.

No. of the mortar.	Composition of the mortar.	Number of days which they took to harden.	Weight which they supported before breaking.
			lbs.
1	Strasburg lime, 1 vol., sand, 1 vol., trass, 1 vol.....	5	411
2	Strasburg lime, 1 vol.....trass, 2 vol.....	4	330
3	Strasburg lime, 1 vol., sand, 1 vol., pozzuolana, 1 vol.	4	499
4	Strasburg lime, 1 vol.....pozzuolana, 2 vol.	3	444
5	Vasselone lime, 1 vol., sand, 1 vol., trass, 1 vol.....	5	449
6	Vasselone lime, 1 vol.....trass, 2 vol.....	4	385
7	Brunstat lime, 1 vol., sand, 1 vol., trass, 1 vol.....	5	510
8	Brunstat lime, 1 vol.....trass, 2 vol.....	4	535
9	White marble lime, 1 vol., sand, 1 vol., trass, 1 vol.....	5	308
10	White marble lime, 1 vol.....trass, 2 vol.....	4	407
11	White marble lime, 1 vol., sand, 1 vol., pozzuolana, 1 vol.	4	396
12	White marble lime, 1 vol.....pozzuolana, 2 vol.	3	367
13	Strasburg lime, 1 vol.....pozzuolana, 2 vol.	4	495
14	Strasburg lime (paste), 1 vol.....pozzuolana, 2½ vol	5	550
15	Strasburg lime (paste), 1 vol.....trass, 2 vol.....	3 to 16	231 to 580

Lime with trass mortars.

560. Experiments seem to prove that fat lime slaked to powder will give better mortars with trass and sand, or with trass alone, if left exposed to the air for a month or more after slaking, than if made into mortar when perfectly fresh; and also that a mortar composed of one volume of lime powder and two volumes of trass, is injured if

a portion of the trass be replaced by sand. General Treussart also found that air slaked lime did not give as good results as lime slaked to powder with water.

CHAPTER IX.

561. *White alkaline effloresences* upon the surface of brick walls laid up in mortar, of which natural hydraulic lime or cement is the basis, frequently produce a most unsightly appearance, and offer a grave objection to the use of cement for masonry exposed to view, or where it is desired to preserve any agreeable shade or tint, or retain the natural color of the brick employed.

Effloresences on brick walls laid in cement mortar.

562. On stone, these effloresences never attain a formidable aspect, and with the denser varieties are almost imperceptible, being confined exclusively to the pointing of the joints; but on brick work, they not unfrequently spread themselves over the entire surface of the wall.

Never formidable on stone walls.

563. A more serious objection than any due to appearance simply, is furnished by the fact that the crystallization of these salts within the pores of the bricks, into which they have been absorbed from the mortar, is certain to cause disintegration. Even stone, particularly the most porous varieties, is not exempt from the effects of this destructive agent, which acts, especially the soda salts, in many respects like frost.

Injury from crystallization.

564. The exudation of those alkaline solutions, which, in crystallizing, produce deleterious salts, appears to be favored by a humid state of the atmosphere, and is, therefore, more prominently developed on the sea-shore than in localities more inland.

Favored by humid atmosphere.

565. *At Newport, R. I.*, pints of it may at any time be collected from the walls of Fort Adams. Being almost entirely soluble in water, it is removed

From Fort Adams.

by rain from all localities exposed to the direct action of this element, to be reabsorbed, in a great measure, before the aqueous solution has time to run off.

Analysis of Fort Adams' efflorescence.

566. A portion of this Fort Adams' efflorescence takes the form of long fibres or needles, frequently projecting more than one inch from the face of the wall. Other portions present the appearance of fine snow. When collected in a mass, it closely resembles Epsom salts in appearance, and is not unlike it in taste. Its composition, as determined by analysis, is reported by Professor Boynton, of the University of Mississippi to be as follows:

Carbonic acid	19.90
Water expelled at a low red heat	52.30
Lime	.04
Soda	27.96
Sulphuric acid	.10
Magnesia	.06
	100.36

From West Point.

567. *Another sample of efflorescence* from the ruins of an embrasure target erected at West Point in the year 1854, subjected to qualitative analysis, gave carbonate of potash as the *principal* ingredient. Its appearance upon the surface of the bricks, resembled that of a thin, rough coating of white sugar. It was readily removed as a powder by scraping.

M. Kuhlmann's experience.

568. *M. Kuhlmann, of Lille*, France, who gave his attention to this subject many years ago, and who has from time to time published his investigations, without proposing any efficient remedy for the evils complained of, notices some efflorescences of a much more complicated composition than those from Fort Adams. Professor Kuhlmann found, that although efflorescences of nitrate of potash (saltpetre), or ammonia, were of no rare occurrence, those of carbonate and sulphate of soda were much more common, and that many stone and brick walls, laid up in hydraulic

mortar within periods quite recent, were covered with exudations of caustic and carbonated potash, containing chlorides of potassium and of sodium.

569. *One source of these salts* of soda and potash is, beyond doubt, the hydraulic lime or cement used in the mortar; derived partly from the stone itself and partly from the ashes of the fuel used in calcination, when the burning takes place in ordinary draw kilns. About 35 lbs. of anthracite coal are required to calcine 1 bbl. (300 lbs.) of cement, and no precaution whatever is taken to separate the coal ashes. From the same cause, the cement also becomes adulterated with fine particles of unconsumed coal, amounting sometimes to three or four per cent. of the whole. When the cement is coarsely ground, these particles are plainly visible, but in the condition of impalpable powder, they are lost to the naked eye.

Source of the soda and potash.

570. Proximity to the sea, where the atmosphere is a constant source, will account for the preponderance of carbonate of soda in the walls of Fort Adams, as well as for the exceedingly large volume of efflorescence. It seems improbable that the mortar could be the origin of so much alkali.

Proximity to the sea favors efflorescence.

571. Three plausible methods of obviating the appearance of these salts suggest themselves:

First, to add some chemical re-agent that will permanently fix them within the body of the mortar by converting them into insoluble compounds.

Remedies.

Second, to render them deliquescent either before, or after they form those compounds that effloresce.

Third, to saponify them by adding some oily substance.

572. Under the *first method*, potash can be managed very well. Hydrofluosilicic acid converts it into a well-known insoluble compound, while the action upon the soda, if present, is not disadvantageous. Potash, however, is harmless in its effects, compared with soda. The sulphate of soda, likely to be formed

in the vicinity of large cities, from the absorption of the sulphuric acid gas, acts like frost in crystallizing.

573. The *second method* does not seem to give promise of success.

574. The *third method*, on the contrary, does promise success, and our trials under it have been numerous. We have found it convenient to make common lime the vehicle for conveying the fatty substance to the cement, and here take occasion again to call attention to the fact that lime paste may be added to a cement paste in much larger quantities than is usually practised in important works, without any considerable loss of tensile strength or hardness. There is no material diminution of strength until the volume of lime paste becomes nearly equal to that of the cement paste (see Tables XXXVII. and XXXVIII.), and it may be used within that limit without apprehension, under the most unfavorable circumstances in which mortars can be placed.

575. To secure a complete dissemination of the fatty matter, it should be mixed up with the caustic lime, so that the heat and other phenomena developed in slaking will complete the incorporation. Its amount will depend upon the proportion between the cement and lime pastes in the mortar, and may vary between 5 and 10 per cent. of the weight of the quicklime, when the latter is employed simply as a vehicle.

Lime in this connection.

576. In examining and judging results, in order to avoid errors, to be apprehended from the minute quantity of alkali generally present in cement, and from the apparently precarious law which seems to control its appearance in the efflorescent state, the amount of alkali was, in many cases, greatly increased, (sometimes several hundred per cent.,) by adding to it from a solution of the salts taken from Fort Adams. This solution was mixed with the water used for making the mortar. With the mortar thus prepared, bricks were cemented together and laid

Method of conducting the trials.

away in pairs, some of them being moistened occasionally, and others left dry. Cakes of the mortar not in contact with brick were also preserved.

In all cases where there was any considerable excess of the alkaline ingredients, a plentiful crop of crystals appeared on the surface within a day or two after the mortar was prepared. No additional efflorescence took place after these were removed. In no case was there any efflorescence from mortar containing the fatty substance, but to which no saline ingredients had been added. It is believed that the proportion of the several ingredients in practice should be from 8 to 12 pounds of the fatty substance to 100 pounds of quicklime, and 300 pounds of cement powder. The cheapest kinds of animal fatty matter will answer.

577. It would not be safe to pronounce at once in favor of this method of remedying the evils of efflorescence. It certainly appears to give promise of success.

INDURATION OF MORTARS OF FAT LIME.

578. We have indicated, paragraph 331, that the hardening of fat lime mortars could be partially attributed to the absorption of carbonic acid gas, producing carbonate of lime ($CaO.CO_2$). The lime absorbs only about one-half the quantity of carbonic acid (CO_2), necessary to convert the whole into carbonate of lime; or, in other words, only about one-half of the lime becomes thus converted, the formula for the hydrate present being $CaO.CO_2 \times CaO.H$. But the hardening of the fat lime mortars cannot be entirely attributed to the formation of carbonate of lime. For we know that mortar, in the centre of thick walls, which never becomes carbonated, nevertheless possesses a fair degree of adhesiveness and hardness. Some mortars, 300 years old, examined in Dresden by Petzholdt, yielded a strong lime water when digested in fresh water, and must therefore have con-

Absorption of carbonic acid.

tained caustic lime. Another portion of the same mortar effervesced freely with cold dilute muriatic acid, and after a few minutes yielded a stiff jelly, proving the previous combination of lime and silica. Analysis of mortars of fat limes and silicious sand 100 years old, and of the limes which furnished them were also made.

579. *From the experiments of Petzholdt*, certain conclusions were drawn:

1st. That there was more soluble silica in the lime mortar than in the original lime.

2d. That there was three times as much soluble silica in the mortar three hundred years old, as in the mortar one hundred years old, and consequently,

3d. That there must have been a chemical combination between the lime and the silicious sand.

4th. The presumption is that the silicious compound formed, acted as an indurating agent.

Mortars containing calcareous sand only.

But we do not find in these trials a reason for the induration of mortars containing none but calcareous sand. Analyses do not prove a chemical combination between the lime and the raw limestone composing this sand, and we must therefore look to the crystallization of the hydrate of lime during the process of desiccation, for the cause of the hardening in this case.

Ordinary mortar a mechanical mixture.

580. *The gang of ordinary lime* mortars is a mechanical mixture of a paste of hydrate of lime and lime water, and in drying, small crystals of soluble lime are deposited on the adjacent surfaces, and adhere with such force to them, as to increase very materially the strength of the aggregates, when the surfaces become closely approximated, as is the case with mortars. In practice, the proportion of sand would be such, that the hydrate will form the thinnest possible stratum between the grains. Mortars containing a deficiency

of sand, indurate very slowly. Wherever the soluble lime comes in contact with air, or even with water, carbonic acid is absorbed, and subcarbonates formed, which accounts for the superior hardness of the surface of mortars. When carbonic acid is thus absorbed, its chemical equivalent of water escapes from the hydrate; hence the dampness of newly-built walls, and newly-plastered rooms. To the foregoing causes collectively, therefore, to wit: the chemical formation of silicate of lime and carbonate of lime, and the crystallization of the hydrate between and upon the surfaces of the sand, we must ascribe the solidification of common mortars.

581. *Mortars of common lime*, suitably compounded, "set," or lose their plasticity in a very few days, and acquire strength with such rapidity, that in the erection of the largest edifices, there is no occasion to wait for the mortar to harden. They become sufficiently strong to resist a powerful force of compression long before they exhibit any adhesion to the solid materials. Such mortars obtain their maximum strength and hardness only after the lapse of years and even centuries.

Setting of mortars of common lime.

THEORY OF HYDRAULIC INDURATION.

582. The ingredients of hydraulic limestones may be separated by analysis into two distinct classes of substances:

1st. Ordinary carbonates of lime, of magnesia, and of the oxides.

2d. Various silicates, that is, combinations of silica with alumina, lime, magnesia, the alkalies, &c.

Ingredients of hydraulic limestone.

Not unfrequently, the only ingredient, except those of the first class, is almost pure silica.

In burning, the first effect is to expel carbonic acid; the second, to effect a combination between the lime, magnesia, &c., thus liberated, and a portion of the silicates or silica, producing com-

First effect of burning.

pounds having an excess of base, and therefore easily attacked by acids. In fact, burnt hydraulic lines are generally quite soluble in acids, leaving gelatinous silica. Another portion of the silica remains uncombined until it is brought into contact with lime in the presence of water, when it unites with the lime held in aqueous solution.

583. A lengthy discussion of the reciprocal actions of the several substances entering into the composition of hydraulic mortars, which take place during the burning of the stone, and the subsequent induration of the mortars, will not be attempted. A brief reference to the parts played by the principal ingredients, particularly the lime, magnesia, silica, and alumina, would seem to be required. The hydraulicity of mortars is the result of combinations between these substances, effected or commenced during the calcination, in the production of compounds which become hydrated in the presence of water, and afterwards undergo a species of crystallization, technically termed "setting." The reactions begun by the agency of heat, are therefore continued and perfected by the agency of water.

Theory of hydraulic induration continued.

584. *We will first take a silicious limestone* for example, capable of producing fair hydraulic lime, as distinguished from cement, like many of the beds found in the calciferous sand rock, (paragraph 9), containing carbonate of lime in excess, and silica in every stage of subdivision, ordinarily found in fine quartzose sand. If the several ingredients are homogeneously mixed in the raw stone, a proper, that is to say, a complete calcination of this stone results in a combination of all the silica, not in the state of inert sand, with its equivalent of lime. The resulting hydraulic lime will contain free caustic lime, inert sand, and a silicate of lime, of which the formula in the general case will be $SiO_3.3CaO$. The hydraulic virtue of this variety of lime is derived in a great measure from this silicate. When mixed into a paste with fresh water, the silicate combines with six

Products of silicious limestones.

equivalents of that substance, producing the hydrosilicate of lime ($SiO_3.CaO+6HO$). All our experience and researches go to prove that silica plays a most important part in the solidification of hydraulic limes and cements, and that the degree of hardness attained depends on the molecular condition of the silica, and the amount of base which ultimately combines with it. In the formation of silicate of lime, the limit of saturation should never be reached, for this requires two equivalents of silicic acid (silica) to three of lime ($2SiO_3.3CaO$), and contains .48 of lime and .52 of silica—a compound possessing no hydraulicity at any stage of calcination, and containing double the proportion of silica deemed most advantageous for mortars. From analyses of mortars of the Theil hydraulic lime, it was discovered that the hydrosilicate contained .25 of silica, .47 of lime, and .28 of water. Besides the silicate of lime formed during the calcination, there is another, formed by a transfer of soluble lime to the silica, which, from the heterogeneous character of the stone, does not combine under the influence of heat.

585. *If the limestone contains alumina in addition to the silica*, or, in other words, if clay be one of its constituent elements, in proportions suitable for ordinary hydraulic lime, carbonate of lime still being in excess, the reactions which take place during the calcination and the quality of the resulting product will depend on the intensity and duration of the heat. When this is simply sufficient to expel all the carbonic acid, a separate and independent combination of lime with silica and alumina takes place during the burning, producing silicate and aluminate of lime, both of which become hydrated by taking up six equivalents of water. The resulting hydrosilicates are represented by the formulas

The reactions when alumina is present.

$$SiO_3.3CaO+6HO, \text{ and}$$

$$AlO_3.3CaO+6HO.$$

Synthetical experiments appear to indicate that the aluminate is the least stable of these two substances.

Effect of augmenting intensity and duration of heat.

586. *If we vary the conditions of calcination* in the last mentioned case, by augmenting the intensity and duration of the heat to that degree necessary to cause partial vitrification of some portions, but not of all, the product becomes heterogeneous. In those portions burnt the most, the silica, alumina, and lime are combined together by the heat under certain reactions that at present appear to be rather obscure. This is more especially the case, when other substances are present, which may act as fluxes. MM. Chatoney and Rivot incline to the opinion that the silicates of alumina and of lime are both formed, and that these compounds, in the presence of water, are decomposed, the results being aluminate and silicate of lime, which become hydrated by combining with three equivalents of water. In that case, the formula for these compounds will be $Al_2O_3.3CaO+3HO$ and $SiO_3.3CaO+3HO$. The fact that these chemical reactions require for their completion only half as much water as when the heat is less intense during the burning, may be intimately connected with the superior hardness of some of the gangs made from vitrified cement.

In those portions least burnt, the aluminate and silicate of lime are separately formed by the action of heat, and these combine directly with 6HO, as in paragraphs 584 and 585.

The reactions when the clay is in excess.

587. *If we suppose the clay to be in excess* in the limestone, as is generally the case with marls, a moderate burning, just sufficient to expel the carbonic acid, causes a separation between the alumina and silica of the clay, the alumina remaining practically inert, while the silica combines with the lime, producing $SiO_3.3CaO$. This becomes hydrated by taking up six equivalents of water, producing a hydrated silicate of the same composition as that recorded in paragraphs 584 and 585. A high heat produces rather complicated and obscure reactions on this class of sub-

stances. A partial triple combination of alumina, silica, and lime takes place during the burning, and the compounds thus formed become hydrated under conditions not very thoroughly understood.

588. The setting of mortars of fat lime and pozzuolana, natural or artificial, is likewise due to the formation of hydrated compounds of lime with silica and alumina. The lime attacks the silica and alumina, freeing them from previous combinations, when such exist, and slowly forms with them $SiO_3.3CaO$, and $Al_2O_3.3CaO$.

Mortars of fat lime and pozzuolana.

589. It has been recommended to allow these mortars to remain mixed for some time, before tempering them just previous to use, a precaution which rests upon a plausible, and doubtless, a sound theory; for while the combinations of lime with silica and alumina previously exist in the hydraulic limes and cements, (having been formed during the calcination and are, therefore, in condition to become hydrates at once, in presence of water,) the conditions are quite different with mortars of fat lime and pozzuolana, in which the silica and alumina have to first free themselves from combinations peculiar to, and existing in the pozzuolana before they can form in the wet way those compounds, which afterwards become hydrates, and confer hydraulicity. From this we can comprehend why fat lime should be used in preference to hydraulic lime for pozzuolana mortars, since the compounds formed during the burning of hydraulic lime will have become hydrates, and will have initiated the hydraulic set, before those formed in the wet way between the free caustic lime and the pozzuolana will have completed the preliminary decomposition: and because, for the same reason, if we employ hydraulic lime, it is only the excess of caustic lime in it that combines advantageously with the pozzuolana. The operation in the mortar of two dissimilar powers, one *composing*, and the other *decomposing* in character, might operate

To remain mixed some time before tempering for use.

disadvantageously. The conditions should be such, that the different combinations of the lime with the silica and alumina, no matter how, when, or where formed, should become hydrated simultaneously.

590. *Magnesia plays an important part in the setting of mortars* derived from the argillo-magnesian limestones, such as those which furnish the Rosendale cements. The magnesia, like the lime, appears in the form of the carbonate ($MgO.CO_2$). During calcination, the carbonic acid (CO_2) is driven off, leaving protoxide of magnesia (MgO) which comports itself like lime in the presence of silica and alumina, by forming silicate of magnesia ($SiO_3.3MgO$) and aluminate of magnesia ($Al_2O_3.3MgO$). These compounds become hydrated in the presence of water, and are pronounced by both Vicat and Chatoney to furnish gangs which resist the dissolving action of sea-water better than the silicate and aluminate of lime. This statement is doubtless correct, for we know that all of those compounds, whether in air or water, absorb carbonic acid, and pass to the condition of subcarbonates, and that the carbonate of lime is more soluble in water holding carbonic acid, and certain organic acids of the soil in solution, than the carbonate of magnesia. At all events, whatever may be the cause of the superiority, it is pretty well established by experience, that the cements derived from the argillo-magnesian limestones furnish a durable cement for constructions in the sea. In Marshal Vaillant's report to the French Academy of Sciences, from the Commission to which MM. Chatoney and Rivot's paper was referred in 1856, this superiority of the magnesian hydrates is distinctly asserted; but the Commission appear to have been led to erroneous inferences in regard to the conditions under which it is expedient or possible to take advantage of this property. We quote from the first part of their report, as follows:

Action of magnesia on the setting of cements.

"On pourrait en conclure qu'il serait utile de remplacer la chaux par la magnésie pour fabriquer les mortiers hydrau-

liques; mais la magnésie n'est pas assez répandue dans la nature pour qu'on puisse l'employer à l'exclusion de la chaux dans les constructions à la mer. En tout cas, il faut proscrire avec soin le mélange de ces bases, c'est-à-dire l'emploi des calcaires magnésiens, attendu que les silicates et aluminates formés par la magnésie ne s'hydratent pas avec la même vitesse que ceux formés par la chaux, et qu'ils risquent d'ailleurs d'être partiellement décomposés aprés l'immersion par la chaux restée en excès, si le mélange n'a pas été longtemps digéré au préalable dans une faible quantité d'eau. En d'autres termes, ces mortiers ne présentent aucune homogénéité, aucune chance de stabilité dans la prise."

Opinion of Marshall Vaillant.

It is needless to say that the "careful proscription" of "magnesian limestones" so forcibly inculcated in this quotation is altogether too comprehensive. While we are not prepared to say that the double carbonate of lime and magnesia, called dolomite, containing a single equivalent of each of the bases, although eminently hydraulic, could, in practice, be relied upon for hydraulic mortars, even in localities where the supply is sufficiently abundant for such a purpose, yet it is certain, that many magnesian limestones, especially those which contain clay, do furnish good cements, and that the Rosendale brands, our chief and best reliance in the United States, are derived from this class, and are by no means open to the objection advanced above, viz.: that they offer "neither homogeneousness nor chance of stability in setting." Some portions of the deposit of Rosendale cement stone contain as high as .39 of carbonate of magnesia to .40 of carbonate of lime; others, as low as .1448 of carbonate of magnesia, to .2848 of carbonate of lime. Between these extremes are found numerous intermediate proportions.

591. Recent analyses of American cements show that they all contain more or less of the alkalies, sometimes caustic and sometimes in the form of chlorides of sodium and potassium. The chlorides are

American cements contain alkalies.

present in all the Rosendale cements, as well as in those from Shepherdstown, Virginia, and Akron, Erie Co., New York. The alkalies promote hydraulic induration in their own peculiar way. We know that mortars of American cements part with soda and potash when immersed in water, and render the latter alkaline; and that alumina and gelatinous silica are soluble in potash; also that a solution of an alkaline silicate readily gives up its silica to lime. We may therefore presume that the alkalies, particularly the potash, act by first dissolving the silica and then transferring it to lime, at the same time that the water acts by dissolving the lime and carrying it to the silica.

When the silica is in excess.

592. When the silica, present in suitable form for entering into combination, is in excess of the equivalent required by the lime and magnesia, the proportion should be adjusted in practice, as far as possible, by adding paste of fat lime, otherwise the mortar will be deficient in strength and liable to crack. Several prisms ($2'' \times 2'' \times 8''$) were made of the paste of James River cement without sand, and kept in water until they were 320 days old. This cement contains nearly fifty per cent. of silica, although the analysis does not state in what form it exists. Some of the prisms broke in handling. They were all covered over more or less with cracks, were quite brittle, and ranged rather above the average hardness of mortars of pure cement paste as shown by the penetration of the needle. On supports 4″ apart those that remained whole gave an average breaking weight of 346 lbs. The fracture was quite jagged and angular, although each of the small surfaces composing it was in itself, comparatively smooth and conchoidal. The first impact of the needle split most of the prisms, and none of them withstood the second. When the block did not split, the effect of the first impact was to raise up the mortar in thin scales around the needle.

Fig. 56.

The general appearance of the fraction is given in Figs. 56 and 57.

None of the prisms left in the air conducted themselves in this peculiar way, although they gave low breaking weights, the average being only 330 lbs.

Fig. 57.

A paste of this cement is improved by the addition of lime paste, up to the limit of 75 to 100 per cent. Inert silica in cement acts simply as an adulterating agent, and takes the place of so much sand.

THE HARDENING, BY ARTIFICIAL MEANS, OF STONE, BRICK, MORTAR, &c.

593. Within the last twelve or fifteen years, the attention of engineers and architects has been directed, in a manner more than usually active, particularly in Europe, to the destructible character of many of the materials in most common use for the walls of constructions of all kinds. The consequence is, that a variety of methods have been devised, and to a limited extent practised, for increasing their durability.

The hardest stone liable to gradual decay.

594. No material will retain through a long series of years the same appearance as when fresh from the hands of the workman. Even the hardest, most solid and compact rocks, such as granite, sienite, gneiss and the densest silicious rocks, exhibit after long exposure, indubitable evidences of "weathering;" while many buildings erected within the last quarter of a century, of some varieties of the limestone, marble, and sandstone of this country, the Bath, Reigate, and Caen stone of the British Isles, and their corresponding formations on the continent of Europe, are already in an advanced state of decay.

595. Of all the causes of progressive destructibility in stone

Alternations of heat and cold, a cause.

none are more active or more difficult to guard against, than frequent alternations of heat and cold, and of moisture and dryness. However slight a change of temperature may be, all bodies will expand when it is raised, and contract when it is lowered, although some, even among different kinds of stone, are much more sensitive to those variations than others. In the United States, the thermometer will vary 110 to 120 degrees between the severe frosts of winter and the direct rays of the summer's sun; extremes which, operating in conjunction with the presence of moisture in the pores of the solid body, alternating not only with the seasons, but oftentimes, especially in the winter, with the recurrence of night and day, between the opposite conditions of water and ice, cannot but result in a change in the state of aggregation of the body, and, if the latter be more than ordinarily porous, in serious disaggregations near the surface. This will be more especially the case, if the mass be made up of several substances of different specific gravities, and of unequal capacity for resisting the expanding power of heat.

596. *The methods devised for increasing the durability of stones, bricks, tiles,* &c., are doubtless equally well adapted to mortar work, such as exterior stucco or concrete, and may with propriety be noticed here. In fact, those modes which now give the best promise of efficacy, base their claims to public support, in a great measure, upon their alleged applicability to such purposes, particularly to the restoration of monuments, statuary, interior and exterior ornamentation, &c.

597. The methods of artificial induration are reduceable to two, as follows:

The general methods of artificial induration.

First. By means of those mixtures or solutions, which, whether applied to the surface with a brush like paint or oil, or by immersing the solid body in them for a longer or shorter time, act simply as mechanical protectives against the penetration of moisture, by forming either an impervious coating upon its surface, or, by penetrat-

ing to a greater or less depth, close up the pores, and render it non-absorbent.

Second. By means of those aqueous solutions, which possess the properties of reagents, and which, when entering the interstices of the solid, give rise to certain chemical reactions by combining with it, or with other and different solutions applied before or after, whereby insoluble solids are produced, and the density and hardness, and consequently the durability and strength of the solid are increased.

Examples belonging to the first method.

598. Among the first class may be noticed a patent "for indurating and preserving stone," granted in England in 1847. The stone to be operated upon was first dressed to the required form, and then thoroughly dried in a heated chamber, or by some other suitable contrivance, to drive off the moisture. The solution, composed of resin dissolved in turpentine, oil, wax, tallow, or some other fatty substance, being brought to the boiling point in a vessel of the requisite dimensions, is retained at that temperature while the stone is immersed in it. Ordinarily, two hours' boiling has been found sufficient to impregnate the stone to the depth of one inch.

A similar process was patented in England in 1853, in the application of which it is recommended to operate upon the stone in air-tight chambers, exhausted, or partially so, of the air, by which means a more thorough impregnation of the material is secured.

Several varieties of indurating mixtures were recommended by the patentee, only two of which we will give. The first is composed of resin dissolved in naphtha, turpentine, or spirits of wine, mixed with gutta percha dissolved in coal-tar naphtha, and when heated, mixed still further with some kind of oil, after which well pulverized "anti-corrosia" is added. Another mixture is made from unslaked lime, to which is added, whilst slaking, oil, or soap fat, and Russia tallow. When the slaking is completed, the whole is placed in a vessel with alum water,

pulverized "anti-corrosia," and proto-sulphate of iron, and a solution made from potatoes and beer settlings. After settling, the solution is decanted for use.

Another patented process consists in the repeated application, with a brush, of a solution of bee's wax in coal-tar naphtha, which is varied when the natural color of the stone is to be preserved, to white wax dissolved in double distilled camphene.

First method not practicable always.

599. Without discussing the respective merits of these methods, we will simply suggest that no process of indurating and preserving stone, that requires the handling and removing of heavy masses, will ever be likely to reach an extensive application in the United States. The characteristic impetuosity of our people, the very active competition existing in all departments of industry, and the low scale of prices to which this state of things has given birth, excludes the idea that any slow, plodding, and costly method, however valuable and efficacious for attaining a desirable end, can enter into successful competition with one that is more rapid, less expensive, and easy of application. It is also unlikely that any plan for indurating and preserving architectural stonework, that cannot be advantageously executed without complicated appliances, and after the building is erected, will ever become of any practical utility; and it is equally unlikely that any solution of resin, wax, or like substances in the fixed or essential oils, which, whether applied hot or cold, merely remain mechanically interposed in the interstices of the solid body, can ever furnish other than a temporary protection.

Examples belonging to the second method.

600. The methods of preservation which belong to the second class, in which the indurating media are applied in the condition of an aqueous solution possessing reacting powers, rest upon a more scientific basis, and are essentially different from those referred to above. Mr. Fred. Ransome gives the following particu-

lars of a process for which he procured a patent in England: It "consists in the employment of two or more separate solutions, which, by mutually acting upon each other, produce within the pores of the stone an indestructible mineral precipitate. In operating, the stone may either be immersed in, or saturated on the surface with a weak solution of silicate of soda or potash, and afterwards with a solution of chloride of calcium or barium, when an insoluble silicate of lime or baryta is formed in the pores of the stone, rendering it impervious to moisture, and insusceptible of injurious effects from atmospheric influences. Or, instead of a silicate of potash or soda, a solution of sulphate of alumina may be employed, and then, by an application of baryta, a compound of sulphate of barytes and alumina is formed."

Ransome's process.

This process, although apparently closely resembling that recommended by Professor Fred. Kuhlmann, of Lille, briefly referred to in paragraph 551, differs from it in the important particular of its alleged adaptation to all kinds of stone, and of using, in all cases, two solutions instead of one, the increase of density of the stone operated upon, being due to the solid compound formed by the mutual decomposition of the two fluids employed; whereas M. Kuhlmann recommends his process of silicatization to the hardening of soft limestones and marble, whether in the walls of buildings or in the form of monuments, ornamentation, or statuary, to calcareous mortars of all kinds, and to all works of whatever character made of plaster, such as mouldings, casts, &c.

M. Kuhlmann's general process.

601. The following extract is taken from the "Report of the Commission charged by the Minister of Agriculture, Commerce, and Public Works, with the examination of M. Kuhlmann's processes of silicatization."

Report of Commission on Kuhlmann's process.

"*The liquor of flints*—silicate of potash or silicate of soda—is the base of the new process. As far back as the year 1840,

some examination into the origin and nature of the efflorescences on walls, had given M. Kuhlmann an opportunity to establish, beyond doubt, the presence of potash and of soda in most of the limestones of all geological epochs, in larger proportions in the hydraulic limestones than in those suitable for common lime. What influence can they exert upon the hydraulic property? M. Kuhlmann is of the opinion that, under the influence of carbonate of potash or of soda, the silicious limestones give rise by calcination, to double combinations of lime, of silica, or alumina, with an alkali, analogous to those obtained by the calcination of some species of hydrated minerals, such as the apophyllite, the stilbite, and the analcime; that these compounds, subsequently put in contact with water, undergo a reaction analogous to that which causes the consolidation of sulphate of lime, viz.: a hydration, and as a consequence thereof, an induration.

"The principal effect produced by the potash and the soda, is to convey a certain portion of silica to the lime, giving birth to silicates, which, while they absorb the water with avidity, retain only such quantity of it as is necessary for their composition as hydrates, and for their induration. Numerous facts support this theory: fat lime, placed in contact with a solution of silicate of potash, is immediately transformed into hydraulic lime; mortars of fat lime, injected several times with a solution of alkaline silicates are transformed into hydraulic mortars; lastly, with the vitreous alkaline silicate, and lime more or less energetic, hydraulic cements can be produced, which can be utilized in localities where none but fat lime is found in the quarries.

Effect of the potash and soda.

602. *Silicatization.—M. Kuhlmann*, by noticing the great affinity of lime for silica, left free in the nascent state, from its combination with potash, was also led to study the action of the silicates of potash and of soda upon the soft limestones and chalk. He noticed the fact, that if chalk is placed in contact, at the ordinary temperature, with a solution of silicate of pot

ash, it is partially changed into a silicio-carbonate of lime, while a corresponding portion of potash is displaced; that the chalk gradually hardens in the air, and becomes harder than the best hydraulic cements; that the same chalk, made into a paste with the silicate, possesses the property of strongly adhering to the surface of bodies on which it is applied. He has thereby discovered a mastic suitable for the restoration of public monuments, and for the fabrication of works of moulding. Carrying his experiments still further, he found that the chalk, in the state of rock as found in nature, if repeatedly immersed in a solution of silicate, and alternately exposed to the action of the atmosphere, is capable of absorbing a considerable quantity of silica, and after some time acquires great hardness on its surface; that the induration, at first superficial, penetrates by degrees towards the centre, so much so that a sample, experimented upon fifteen years previously, and placed before the Commission for inspection, had acquired that induration to a depth of nearly one centimetre (.39 in.) This "silicatization," as M. Kuhlmann styles his process, is due to the decomposition of the silicate of potash, partly by the carbonate of lime, and partly by the carbonic acid of the air. A solution of silicate of potash left in the air, will, in effect, after some time, form a gelatinous and contractible deposit of silica, and a layer of carbonate of potash. The deposit of silica acquires, after some time, a hardness sufficient to scratch glass. Of two balls of chalk of the same size and quality, both silicatized in the same manner, the one left in the open air acquires a greater hardness than the other placed under a glass receiver, where the air is free from carbonic acid. By this process, therefore, there is formed a kind of a hydrated silicio-carbonate of lime, which indurates while gradually abandoning its water of hydration, and a contractible deposit of silica, which also augments the hardness of the stone. The carbonate of potash produces on the surface a perceptible exudation or efflorescence, which decreases by degrees, and at last totally disappears, without hav-

ing altered the surface in any manner. By means of the hydrofluo-silicic acid, M. Kuhlmann has succeeded in obviating the inconveniences that may arise therefrom, while he at the same time increases the progressive induration

"Calcareous stones thus prepared assume a compact texture, a smooth appearance, and are capable of receiving a fine polish. The induration is singularly favored by heat. Some porous limestones, immersed in a boiler, under a high pressure, containing a bath of silicate of potash, assumed soon after removal all the characters of compact silicio-calcareous stones, without the slightest intervention of the carbonic acid of the air.

603. "*M. Kuhlmann experimented upon other porous stones*, and observed that the action of the carbonic acid of the air upon silicate of potash, was sufficient to cause on the surface of the stones a consolidation varying in intensity with their porosity.

604. Upon the sulphate of lime or plaster, the action is sensibly the same, but is more rapid, and possesses the inconvenience of giving rise to sulphate of potash, which, by crystallizing, has the property of disaggregating the surfaces. In this case the solution must be more diluted, in order to secure a slower action, although producing a sufficient consolidation for avoiding the effects of the crystallization of the sulphate of potash.

Action on sulphate of lime.

605. "*Mode of application.*—The solution of the silicate of potash, as manufactured by M. Kuhlmann for the market, is quoted at 35° by Beaumé's areometer. It is sufficient to dilute it in twice its volume of water, in order to obtain the degree of concentration most suitable for induration. Upon recent constructions, the application can be made without preparation; on old ones, it is preceded by a thorough washing of the surface, using for this purpose a hard brush dipped in a dilute solution of caustic potash. Upon large surfaces, the applications are made with force-pumps or syringes, care being taken to collect, by means of ridges made of potter's clay, at the foot of the wall, the liquid in excess. For sculptures and certain portions of

buildings, soft brushes, or more advantageously pencils, are made use of. Experience has shown that three applications made during three days consecutively, are sufficient to properly harden the stone. The quantity of solution absorbed varies with the nature and porosity of the stone; the cost of the silicate never reaches above 75 centimes per square mètre (12 cts. per square yard) for the most porous stones."

606. "This process, having been applied to the new sculptures of the Lille Bourse, to the works of restoration of St. Maurice Church, to the construction of a new church at Wazemmes, to the Séclin Hospital, in some works of military engineering, and in private constructions at Lille, has completely succeeded." Examples.

607. "As early as 1841, MM. Benvignat, Marteau, and Verly witnessed the efficacy of this process. It was also practised elsewhere, at Versailles, Fontainebleau, the Chartres Cathedral, the Lyons City Hall, the Louvre, and Notre-Dame at Paris. Very able engineers, such as MM. Lassus, Lefuel, and Violet-Leduc, have obtained from it the most satisfactory results."*

608. "*Stone Dyeing.*—M. Kuhlmann observing that the silicatization of constructions and sculptures gives rise to various discolorations which showed the joints more distinctly, was led to find a remedy for this defect in his process. By means of the double silicate of manganese and potash, he obtained a blackish solution applicable to calcareous stones of too light a color. By diluting in the silicious solution some artificial sulphate of baryta, those limestones Management of the color.

* Although proofs, apparently the most conclusive, of the efficacy of the alkaline silicates as indurating agents, may be multiplied, the subject still appears to be surrounded with practical difficulties; and the advocates of the new theory meet at every turn reports of unsatisfactory results or mortifying failures. The "London Athenæum" of August, 1859, contains a statement that the exterior walls of *Notre Dame*, and the *Palace of the Louvre* are in a very unsatisfactory condition, that the rains had apparently destroyed the preservative powers of the silicate, before the surface had, by the absorption of carbonic acid gas, attained a degree of hardness sufficient to resist their action.—AUTHOR.

that are too dark are lightened up. He found that the porous limestones submitted to ebullition in solutions of metallic sulphates of oxides, insoluble in water, cause the fixing, at a certain depth, of said oxides in intimate combination with the sulphate of lime. With sulphate of iron, he obtains a rusty color more or less dark; with sulphate of copper, a magnificent green dye; with sulphate of manganese, brown hues; with a mixture of the sulphates of iron and of copper, a chocolate color, &c. He also observed that the double sulphates thus formed penetrate into the stone and also increase its hardness."

THE END.

APPENDIX.

DESCRIPTION AND ANALYSIS OF THE COST OF SEVERAL QUALITIES OF CONCRETE USED IN THE CONSTRUCTION OF THE FORTIFICATIONS ON STATEN ISLAND, NEW YORK HARBOR, DURING THE YEARS 1870 AND 1871.

DESCRIPTION OF MATERIALS USED.

Portland Cement.—Portland cements from three localities were used during the two seasons, viz., from Stettin, Germany, from Boulogne Sur-Mer, France, and from the Thames, near London, England.

They were found to differ very little in quality. The tests of strength made from time to time showed the Boulogne cement to be a little superior to either of the others, but the difference in this respect was about compensated by its extra cost.

The Boulogne and the London Portland cements used on the Staten Island works through two consecutive seasons, as well as several thousands of barrels received in New York, and tested, either for private use, or for officers of the corps of Engineers located at distant points, have, with one exception, been found to be fully up to the standard exacted by the English and the French Engineers.

The use of the Stettin cement on the fortifications has been

limited to one invoice, which was entirely satisfactory as to quality, but fell short in weight seven pounds to the cask. Inasmuch as manufacturers of Portland cement invariably sell by weight, this difference is of no moment, except to dealers and consumers who purchase by the cask.

STANDARD QUALITY OF THE CEMENTS USED.

Portland cement should weigh not less than 106 lbs. to the struck imperial bushel, loosely measured, and should be ground so finely that at least ninety per cent. of it will pass a No. 35 wire gauze sieve, of 47 wires to the lineal inch each way.

When mixed with fresh water into a paste of the consistency of stiff plasterers' mortar, without sand, and pressed into a mould, it should, at the end of seven days, sustain a tensile strain of 500 lbs. on a sectional area of $2\frac{1}{4}$ square inches, ($1\frac{1}{2}$ inches by $1\frac{1}{2}$ inches) equal to 222 lbs. per square inch, having been kept six days in water. This is a combination of the tests applied by the English and the French engineers, that is, it is the lowest English standard of weight, the highest of tensile strength, and the ordinary French standard of fineness.

Cement of this quality can be made with as much ease and certainty as that of a lower grade, while the increase in the cost of manufacture, due to the consumption of extra fuel and grinding power, is but trifling. As it is not a wise policy to pay ocean freight on an imported cement of inferior quality, the highest standard of excellence should be exacted.

Lime.—The lime was quarried, burned, and ground at Rondout, Ulster Co., N. Y. It is known in the market as Rondout ground lime.

One barrel of this lime (268 lbs. net) produces $2\frac{5}{8}$ bbls. of fine powder loosely measured, when slacked with 15 gallons of water. If water be added in suitable quantities, the $2\frac{5}{8}$ bbls. of loose powder will yield $1\frac{3}{4}$ bbls. of paste of the consistency of plasterers' mortar.

This lime is not pure white, but slightly drab in color, and

although it does not possess any perceptible hydraulic properties, it is generally thought to make a stronger mortar than the white limes.

Rosendale Cement.—The Rosendale cement was from the manufactory of the Newark and Rosendale Company. Its quality ranges rather above the average of American cements. It weighs from 70 to 74 lbs. to the bushel, loosely measured, and when made into a stiff paste without sand, and pressed into a mould, it will attain, in seven days, having been six days in water, a tensile strength of 140 to 150 lbs., seldom greater, on a sectional area of 2¼ square inches, equal to 62 to 66 lbs. to the square inch. It is, like other Rosendale cements, subject to very considerable variations in quality from time to time, and often falls greatly below this test.

Stone.—The stone used in the several kinds of concrete described below, was prepared by crushing ordinary limestone in a Blake's stone-breaker.

The fragments were of all sizes below a two-inch cube, and were of various shapes, being generally quite angular and irregular in form.

This stone cost $2.00 per ton of 2,240 lbs., delivered to the wharf at the fort on Staten Island.

Gravel.—The gravel was the usual mixture of smooth gravel and pebbles from the sea-shore, with the sand screened out. It varied from the size of a pea to that of a hen's egg, and cost $1.60 per ton of 2,240 lbs., delivered on the Government dock at the works.

Both gravel and stone varied in size from time to time with the different cargoes, sometimes running a little larger, and frequently much smaller, than the general average given above, requiring corresponding changes in the proportions used for making concrete. The mixture containing the least measure of voids was the one constantly sought, and it was always found between the limits of eleven and fifteen volumes of stone, to fifteen of gravel, that is, fifteen measures of gravel were mixed with from eleven to fifteen measures of broken stone.

The following table gives the proportions of some of the mixtures tried at various times, with different sizes of stone and gravel:

13 measures stone 15 " gravel	voids 23%
15 measures stone 15 " gravel	voids 24%
11¼ measures stone 15 " gravel	voids 25 6/16%
22 measures stone 15 " gravel	voids 26¼%
12 measures stone 15 " gravel	voids 27½%
27 measures stone 15 " gravel	voids 30%

Mill-made concrete, for all the various uses to which it is applied, possesses sufficient superiority in quality over that manipulated by hand, as to justify the expense of suitable power and machinery, when operations of considerable magnitude are to be carried on. The more thorough manipulation secured by machinery enables a smaller proportion of the cementing substance to be used, and effects a saving in the cost of both materials and labor.

Portland cement of good quality, containing no quick-lime and weighing, say, 106 lbs. to the struck bushel loosely measured, requires 42 to 44 per cent. of its volume of water to convert it into a paste of the consistency of masons' mortar. When quick-lime is present, which is often the case with cements when first made, a larger amount of water is needed. Portland cements that have been overburnt, or those that have become injured from age or exposure, by the absorption of moisture from the atmosphere, and the spontaneous conversion into hydrates, of the silicates and aluminates and any excess of quick-lime formed in the kiln, require less water for mixing than they otherwise would.

The following tables show the quantities of paste and mortar of different qualities, some with and some without lime, that can be made with one barrel of cement as the basis:

CEMENT PASTE.

	Boulogne Portland Cement (France).	Water.	Paste produced.
1	1 bbl. (400 lbs. nett) = 1.34 bbls. loose powder	16 gallons	1.17 bbls.
2	1 " " = 1.40 " " "	16 "	1.19 "
3	1 " " = 1.33 " " "	14¼ "	1.12 "

As an average, therefore, from the foregoing table, 1 bbl. of Boulogne Portland cement, as packed for market, will produce 1.35 bbls. of loose powder, and 1.16 bbls. of paste of the consistency of plasterer's mortar.

MORTAR.

	Stettin Portland Cement (Germany).	Sand.	Water.	Mortar produced.
1	1 bbl. = 392 lbs. nett	——	14 gallons.	1.16 bbls.
2	1 " " "	1	17½ "	1.80 "
3	1 " " "	2	20 "	2.54 "
4	1 " " "	3	25 "	3.36 "
5	1 " " "	4	28½ "	4.00 "
6	1 " " "	5	35 "	4.77 "
7	1 " " "	5	—	5.40 "
8	1 " " "	6	42 "	5.70 "

MORTAR.

	Boulogne Portland Cement.	Sand.	Water.	Mortar produced.
1	1 bbl. (400 lbs. nett)	—	16 gallons.	1.12 bbls.
2	1 " " "	1	21 "	1.38 "
3	1 " " "	2	23½ "	2.54 "
4	1 " " "	3	28½ "	3.31 "
5	1 " " "	4	35½ "	4.19 "
6	1 " " "	5	42½ "	4.92 "
7	1 " " "	6	51 "	5.65 "

CEMENT AND LIME PASTE.

	Boulogne Portland Cement.	Ground Lime slaked (powder.)	Water.	Paste produced.
1	1 bbl. (400 lbs. nett) = 1.40 bbls. loose powder.	1.25 bbls.	31 galls.	2 bbls.
2	1 " " " = 1.35 " "	1.25 "	29 "	1.85 "
3	1 " " " = 1.35 " "	1.25 "	27½ "	1.92 "
4	1 " " " = 1.31 " "	1.50 "	33½ "	2.27 "
5	1 " " " = 1.38 " "	1.50 "	32½ "	2.34 "
6	1 " " " = 1.34 " "	1.50 "	32½ "	2.15 "

MORTAR.

	Boulogne Port. Cement.	Slacked Lime powder loose.	Water.	Paste produced.	Additional Sand.	Additional Water.	Mortar produced.
1	1 bbl. = 1.31 bbls. loose pow.	1.5 bbl.	32½ galls.	2.27 bbls.	8	30 ...	7.65 bbls.
2	1 " = 1.38 " "	1.5 "	32½ "	2.34 "	8	27½ ...	7.69 "
3	1 " = 1.34 " "	1.5 "	32½ "	2.15 "	8	33½....	7.54 "
4	1 " = 1.35 " "	2.62 "	—	—	10	...	10.37 "

MORTAR.

	Rosendale Cement.	Sand.	Water.	Mortar produced.
1	1 bbl. (300 lbs. nett).	——	15 galls.	1.05 bbls.
2	1 " " "	1 bbl.	17⅛ "	1.69 "
3	1 " " "	2 "	21 "	2.50 "
4	1 " " "	3 "	25 "	3.27 "
5	1 " " "	4 "	30 "	4.05 "

CONCRETE NUMBER 1.

1 Bbl. German Portland cement (393 lbs.)	$3.45	=5.4 bbls. concrete mortar.
5½ " damp sand loosely measured,	$. 33	
6 " gravel and pebbles from seashore	$1.94	=12½ Bbls. mixed and shaken down containing 26½ per cent. of voids.
9 " broken stone,	$3.28	

One batch of concrete composed as above, makes fifty cubic feet of rammed concrete. This is an average of several batches. This concrete is of first-rate quality, being compact, free from voids, and strong. It is richer in mortar than would be necessary for most purposes.

The cost of the materials for one cubic yard of this concrete delivered at the concrete bed ready for use, omitting the Custom-house duty on the cement, amounts to	$4.86
The cost of mixing, transporting, and ramming the concrete, per cubic yard, amounts to	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$6.55

The cost of labor is based upon the following prices for a day's work of ten hours: sub-overseer, $3.50, mason or carpenter setting plank, $3.80, and laborers, $1.80.

The labor in constructing concrete magazines, in consequence of the extra work in setting the planking at the entrance angles and doors, and in making and setting the centres, and the consumption of extra lumber, will amount to about $1.90 per cubic yard instead of $1.69, as given above.

CONCRETE NUMBER 2.

1 Bbl. German Portland cement (393 lbs.)	$3.45	= 5.7 Bbls. concrete mortar.
6 " damp sand loosely measured,	$ .36	
5 " gravel and pebbles from seashore,	$1.62	Mixed together and shaken down, contains 30% of voids.
9 " broken stone,	$3.28	

One batch of Number 2 makes 50 cubic feet of rammed concrete.

The materials for one cubic yard of concrete Number 2, cost, delivered at the concrete bed,	$4.70
Cost of mixing, transporting, and ramming, per cubic yard,	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$6.39

Concrete Number 3.

1 Bbl.	Boulogne Portland cement (400 lbs.)	$3.45	=7. Bbls. mortar.
1 "	Slaked ground lime in powder,	$ .58	
7 "	loosely measured damp sand,	$ .42	
13 "	Gravel and pebbles from seashore,	$4.20	= 22¾ Bbls. mixed together and shaken down, with 24% of voids.
13 "	Broken stone,	$4.74	

One batch of concrete Number 3 makes 86¼ cubic feet of rammed concrete.

Strength of the mortar. The mortar with which concrete Number 3 is made, composed of 1 bbl. Portland cement, 1 bbl. of slaked ground lime in powder, and 7 bbls. of sand, possesses, when two months old, a crushing strength of 300 lbs. to the square inch, the test being applied to 5 inch or 6 inch cubes.

Cost of concrete Number 3. Cost of materials for one cubic yard,	$4.18
Cost of mixing, transporting, and ramming, per cubic yard,	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$5.87

Concrete Number 4.

1 Bbl.	Boulogne Portland cement, (400 lbs.)	$3.45	=7.9 Bbls.concrete mortar.
1¼ "	Slaked ground lime in powder,	$ .72	
8 "	loosely measured damp sand,	$ .48	
16 "	Gravel and pebbles from seashore,	$5.17	= 28 Bbls. mixed together and shaken down, with 24% of voids.
16 "	Broken stone,	$5.82	

One batch of concrete Number 4 makes 105 cubic feet of rammed concrete, of suitable quality for most kinds of massive work. It contains the greatest admissible proportions of gravel and broken stone. The quality of the concrete would be improved by using 18 barrels of gravel and 14 of broken stone, instead of 16 barrels of each.

Strength of the mortar. The mortar of concrete Number 4, composed of 1 barrel of Portland cement, 1¼ barrels of slaked ground lime in powder, and 8 barrels of sand, possesses a crushing strength of 220 lbs. to the square inch, when two months old, the pressure being applied to 5 inch or 6 inch cubes.

Cost of concrete Number 4. Cost of materials for one cubic yard,	$4.02
Cost of mixing, transporting, and ramming, per cubic yard,	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$5.71

CONCRETE NUMBER 5 (made with Rosendale cement):

1 Bbl.	Rosendale cement (300 lbs.)	$1.77	=3.27 Bbls. concrete mortar.
3 "	Damp loose sand,	$ .18	
5 "	Broken stone,	$1.82	

This batch of concrete, as the average of an entire season's work, has been found to yield 21.75 cubic feet, rammed in position.

Strength of the mortar. The mortar of concrete Number 5, composed of 1 barrel Rosendale cement and 3 barrels of sand, possesses a crushing strength of 130 lbs. per square inch when two months old, the test being applied to 5 inch or 6 inch cubes.

Cost of concrete Number 5. The materials for one cubic yard cost	$4.67
Cost of mixing, transporting, and ramming, per cubic yard,	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$6.36

Concrete Number 5 is the standard quality of Rosendale cement concrete generally adopted upon government works. It possesses sufficient strength in foundations and thick walls for any position in which concrete is usually placed. The nearest approximation to it in quality and strength, of any of the Portland cement concrete used at Fort Tompkins, is concrete Number 6 given below.

CONCRETE NUMBER 6.

In this concrete the proportion of mortar to the broken stone, adopted for the Rosendale cement concrete Number 5, has been carefully maintained.

Portland cement, 1 Bbl.	$3.45	= to 10.37 Bbls. of concrete mortar.
Ground lime, 1 Bbl. producing of lime powder 2⅝ Bbls.	$1.50	
Sand, 10 Bbls.,	$ .60	
Broken stone, 16 Bbls.,	$5.82	

One batch of concrete produces 69½ cubic feet, rammed in position.

Strength of the mortar. The mortar of concrete Number 6, composed of 1 barrel Portland cement, 1 barrel ground lime (producing 2⅝ bbls. slaked powder), and 10 bbls. sand, possesses a crushing strength of 154 lbs. to the square inch when two

months old, the pressure being applied to 5 inch or 6 inch cubes.

Cost of concrete Number 6. Cost of materials for one cubic yard,	$4.41
Cost of mixing, transporting, and ramming, per cubic yard,	$1.37
Lumber and timber, and carpenters' labor in setting up same,	$ .32
Total cost of concrete per cubic yard,	$6.10

This concrete therefore possesses two advantages over concrete Number 5, viz.: the mortar, although used in the same proportions to the broken stone as in Number 5, costs nearly 11 per cent. less, and is more than 18 per cent. stronger.

Hand-made concrete. All the several kinds of concrete described above were made by hand, after the manner indicated in paragraphs 366 to 376.

When lime was used, the slaked lime powder and the dry cement were rudely mixed together on the mortar-bed before the sand and water were added.

Mill-made concrete. The mill used for mixing concrete is a cubical wooden box measuring four feet on each edge in the inside. It is provided on one face with a trap-door about two feet square, close to one of the angles, and is mounted on an iron axle, passing through opposite diagonal corners. An archimedean screw mortar-mill, for mixing the concrete mortar, is used in connection with the box, and both are driven by a small engine of about six-horse power. Eight revolutions of the box, made in less than one minute, are found to be quite sufficient to produce the most thorough incorporation of the mortar with the broken stone and gravel. Every piece of stone, and every pebble and gravel, become completely coated over with mortar.

In making the mortar, the cement, lime, and sand are first rudely mixed together with shovels on the mortar-bed, and are then passed through the mill once; one measure of the dry mixture (about a cubic foot), alternating with one small measure of water.

The precise amount of water necessary is determined by trial, and will vary from time to time with the more or less moist condition of the sand.

Four men with barrows are employed in conveying the concrete materials (the mortar, broken stone, and gravel) into the concrete box, one barrow full of the mortar (2 cubic feet) alternating with three heaped up barrows full of the coarser ingredients (7 cubic feet). The materials are dumped into the box from a staging, erected on the level of the trap-door when at its highest point.

One charge of the box contains:

4 barrows of mortar (8 cubic feet).
6 heaped up barrows of broken stone (14 cubic feet).
6 " " " gravel (14 " ").

After mixing, the trap-door is opened and the contents deposited on the platform below, by two or three revolutions of the box. The concrete box produces such a thorough and complete trituration of its contents, that it is not necessary that the mortar should be mixed beforehand. The mortar-mill, as an auxiliary, may therefore be dispensed with. The ingredients of the mortar (the cement, lime, sand, and water), after being properly proportioned by measure and rudely mixed together with shovels, require no further preparation, but may at once be added to the coarse materials in the box.

The method of charging the box by barrows, practised at the Staten Island works, is not considered the most economical that can be devised.

A crane or derrick worked by the same engine that turns the box, and having a sweep of sufficient length to reach the mortar-bed, and the piles of broken stone and gravel, would doubtless be an improvement.

A concrete box employed by General Duane in Portland Harbor, Maine, is operated in this way.

One box of the capacity above described (4′×4′×4′ on the inside) will mix from 95 to 100 cubic yards of concrete in one day of ten hours, and will do the work very much better than it can be done by hand, and at a saving of from 15 to 20 per cent. in the cost of labor.

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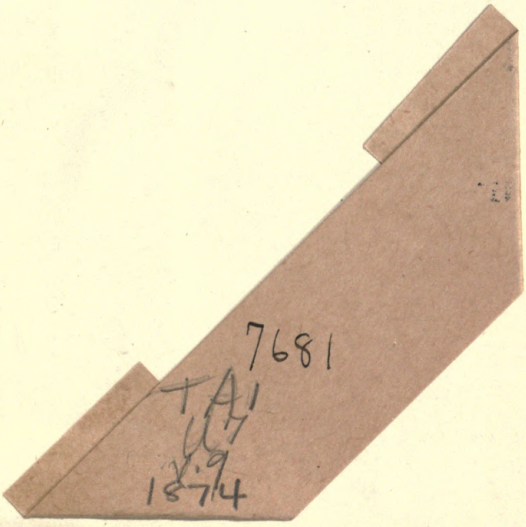
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